Re-creation of species-rich vegetations on former agricultural lands

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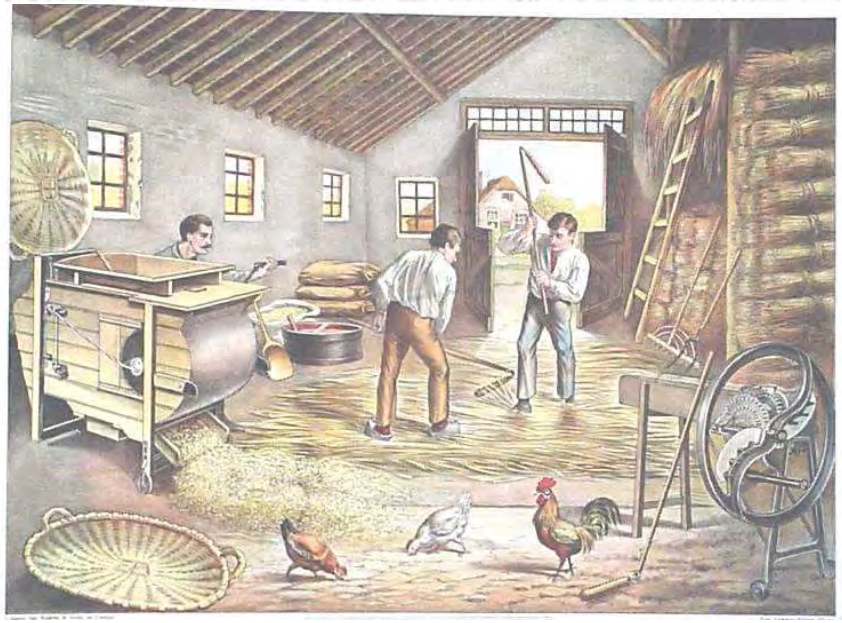
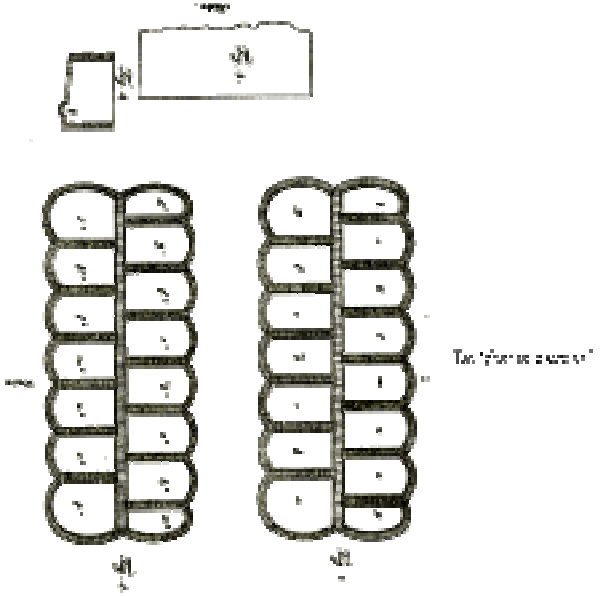
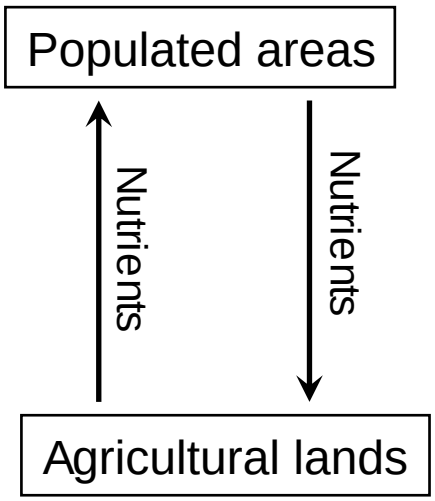
Traditional agriculture: shortage of nutrients



Transport of city waste to agricultural areas



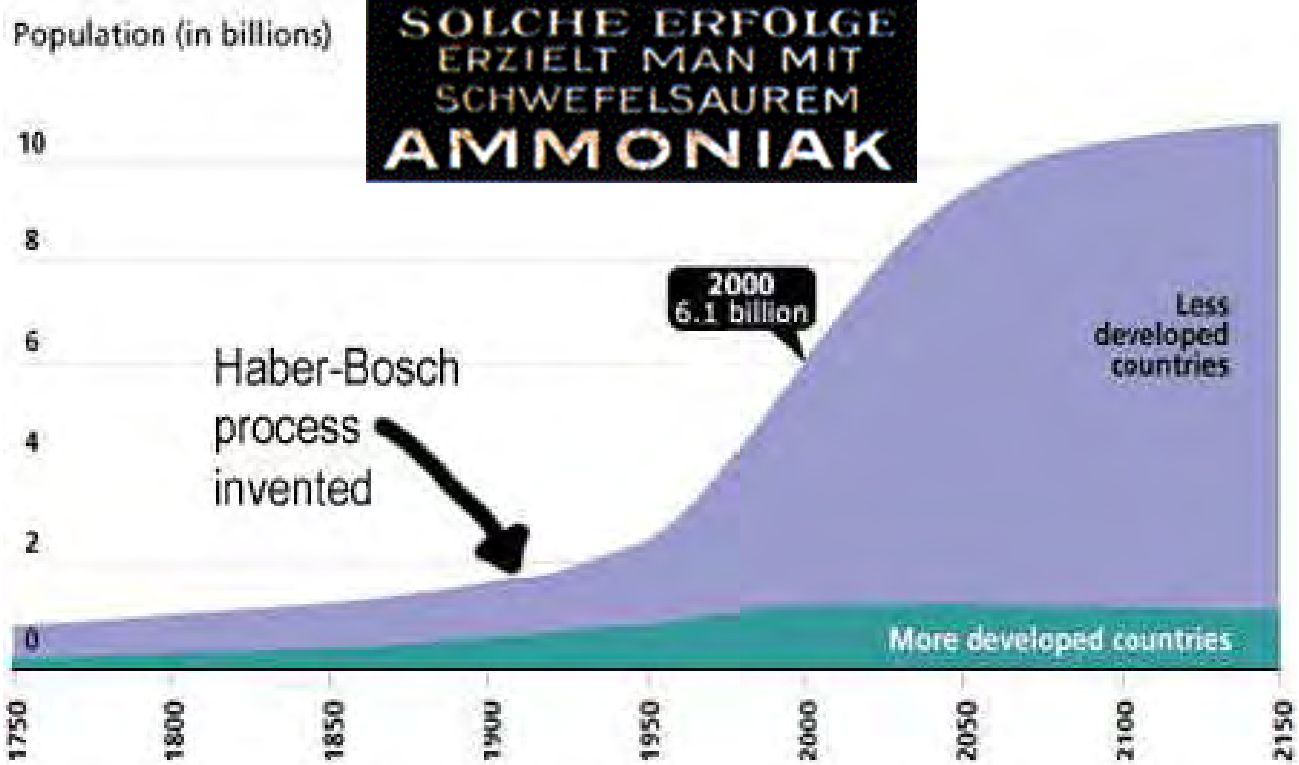


Sod-cutting of heathlands: sods where mixed with animal manure and used for fertilization

Deep litter house (potstal in Dutch)

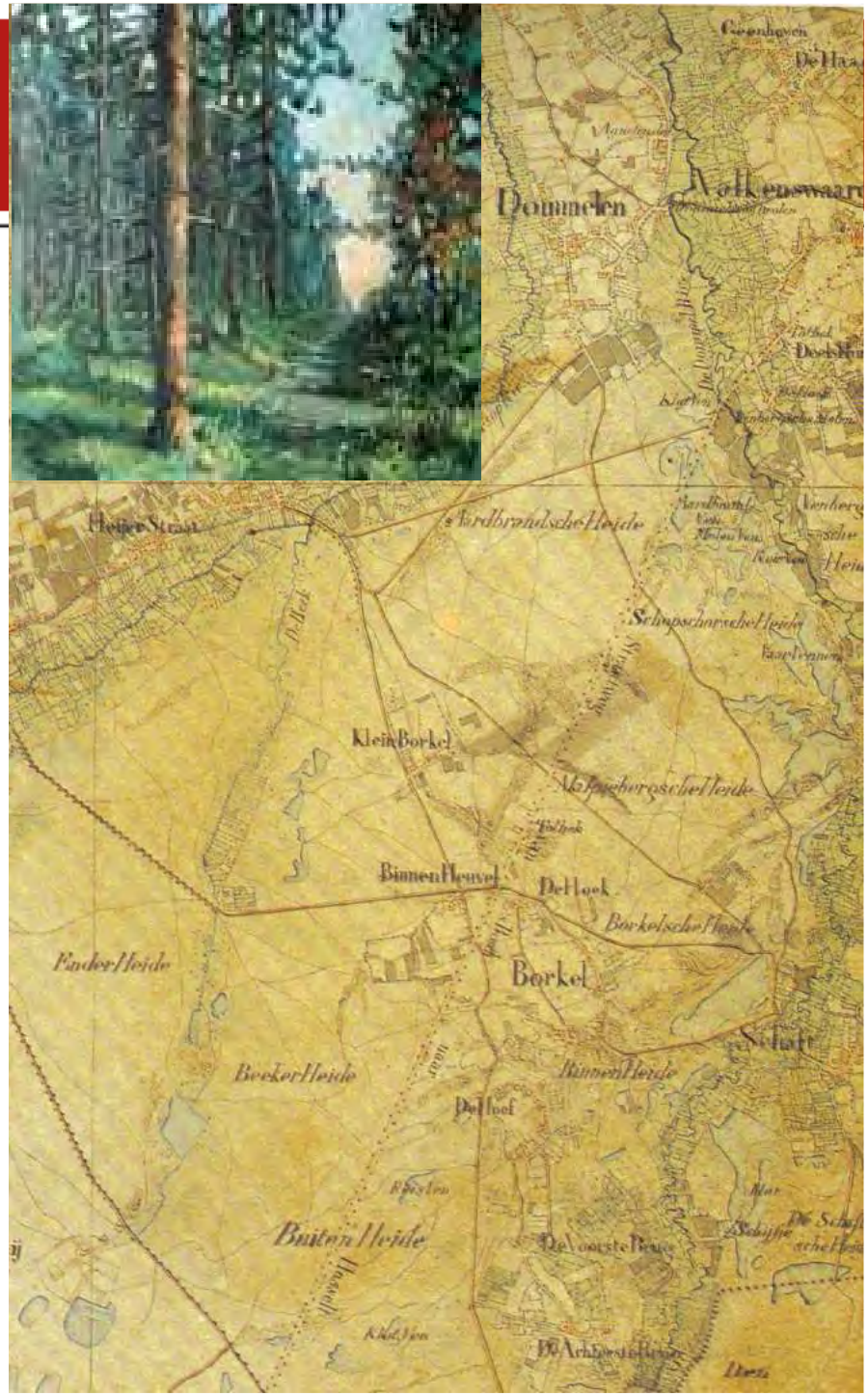
species rich grasslands could persist due to lack of fertilization

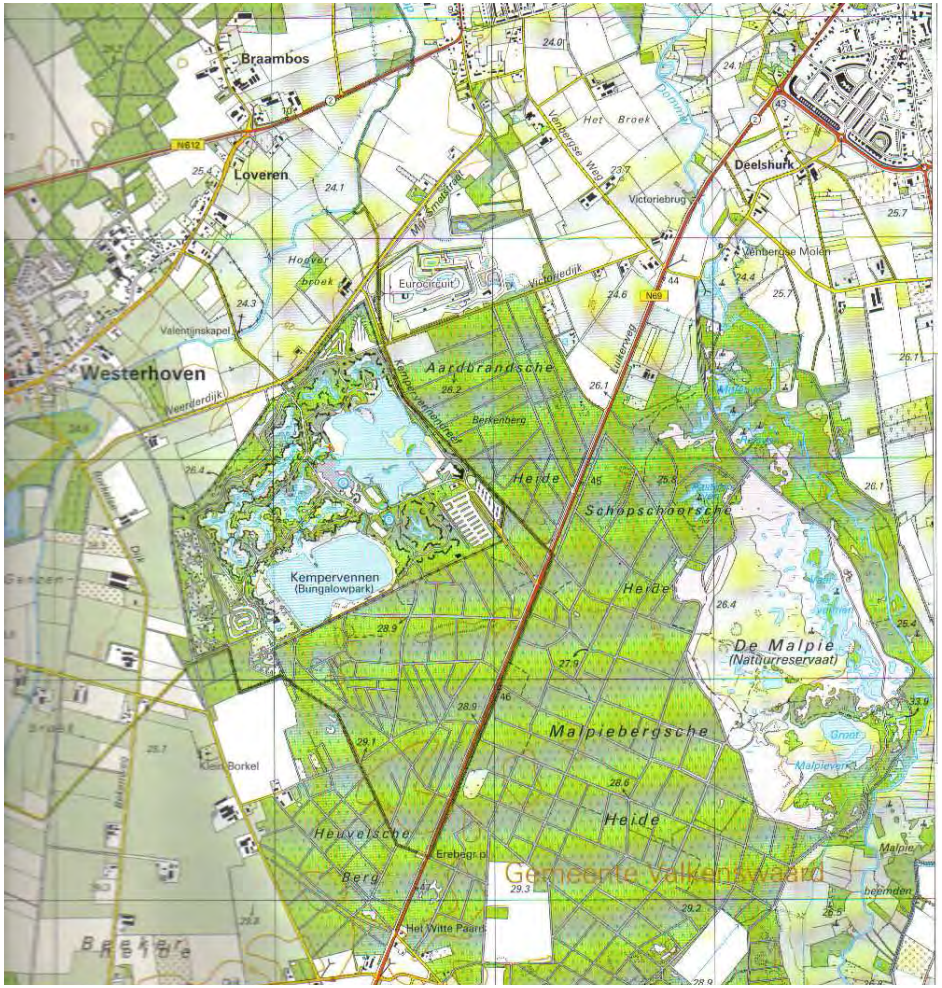
Haber-Bosch process:
Under high temperatures and very high pressures, hydrogen and nitrogen (from thin air) are combined to produce ammonia. Nearly one century after its invention, the process is still applied all over the world to produce 500 million tons of artificial fertilizer per year. 1% of the world's energy supply is used for it *(Science 297(1654), Sep 2002);* it still sustains roughly 40% of the population *(M. D. Fryzuk, Nature 427, p 498, 5 Feb 2004).*
Billions of people would not even exist without it. And our dependence will only increase as the global count moves from six to ten billion people or so.



Changed land use:
heathlands and species rich grasslands have been converted into fertile agricultural lands

Changed land use:
or into pine forest plantation





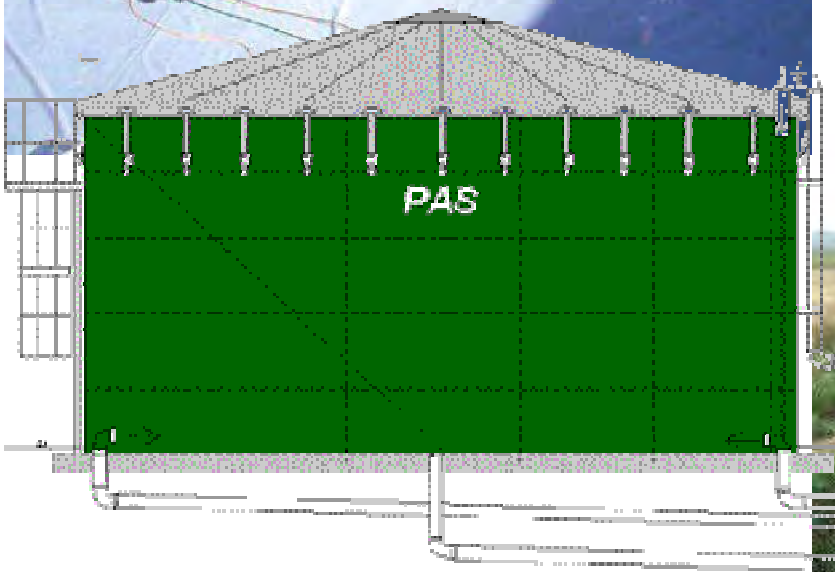
To provide timber to support the mine's roofs.

Intensification of agriculture in the Netherlands:

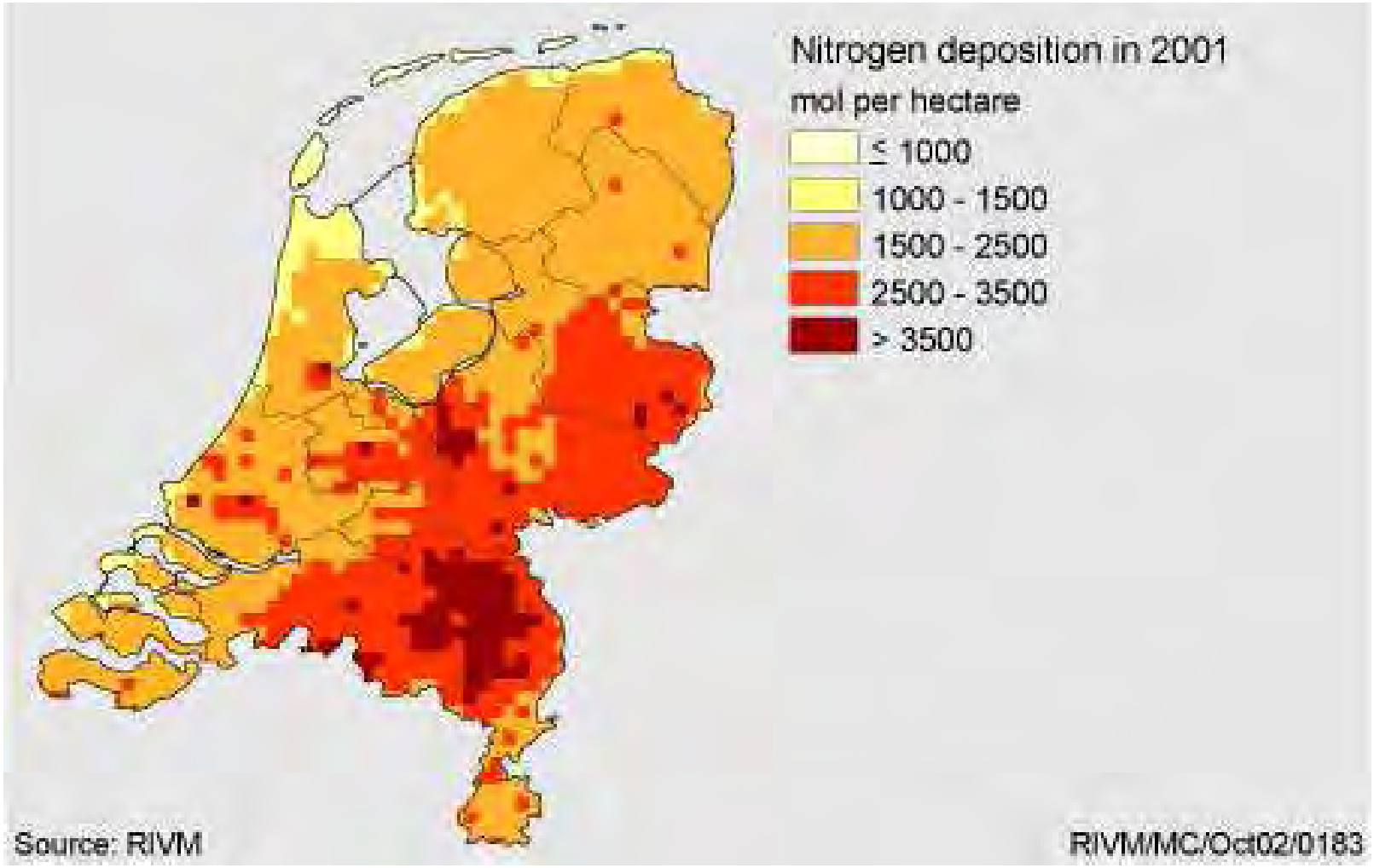
drainage in order to transform wetlands into agricultural lands

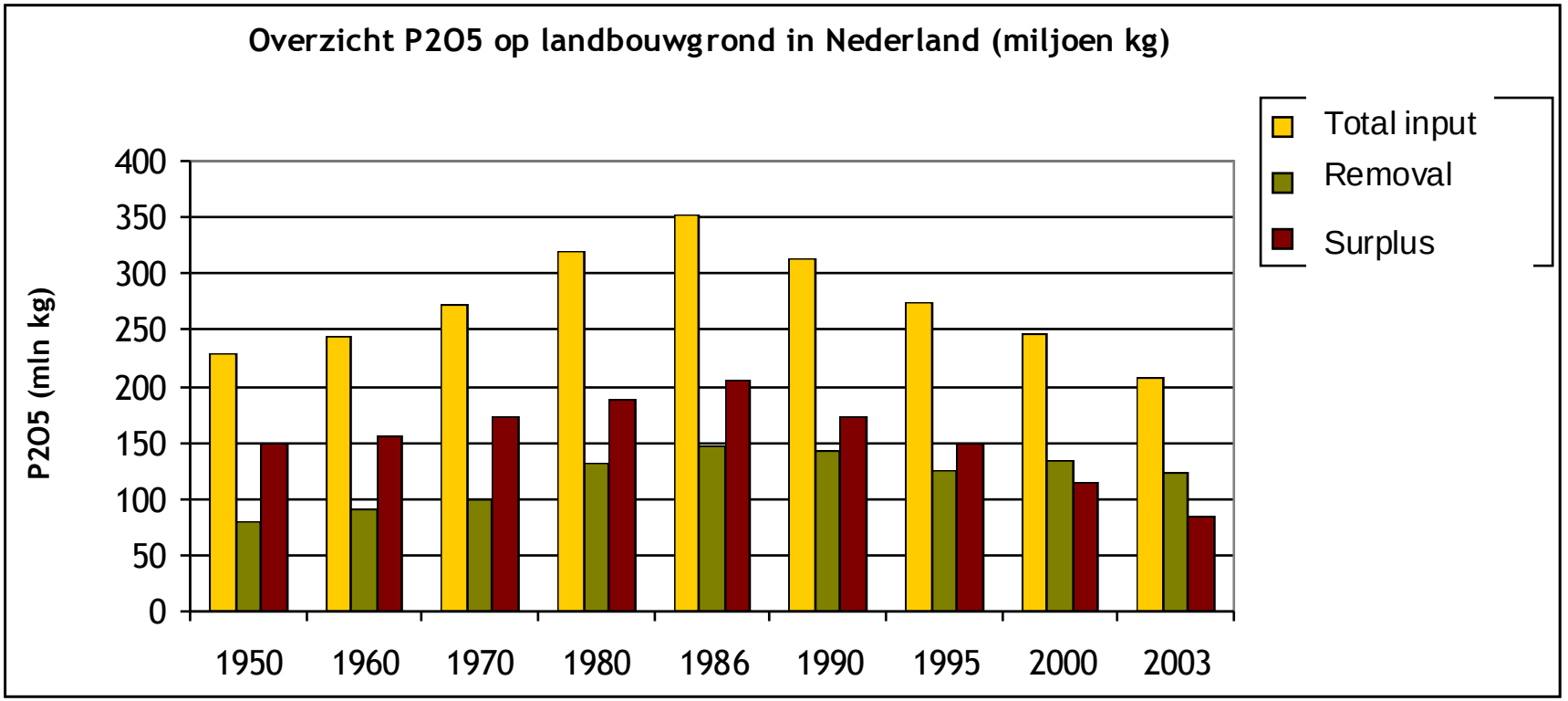
Intensive cattle breeding

Nowadays we have a manure surplus



Strongly increased N and P fertilisation !!


Nitrogen deposition in 2001
mol per hectare
≤ 1000
1000 - 1500
1500 - 2500
2500 - 3500
> 3500
Source: RIVM
RIVM/MC/Oct02/0183

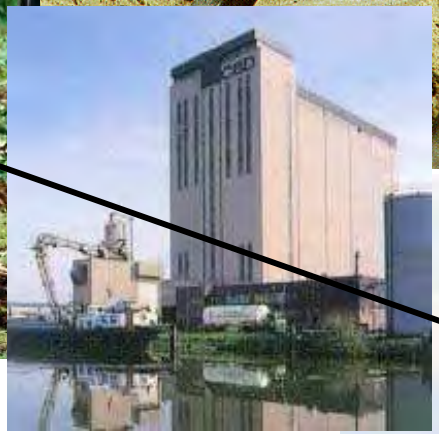

Overzicht P2O5 op landbouwgrond in Nederland (miljoen kg)
P2O5 (mln kg)
400
350
300
250
200
150
100
50
0
1950
1960
1970
1980
1986
1990
1995
2000
2003
Total input
Removal
Surplus

Intensive cattle breeding is world wide problem

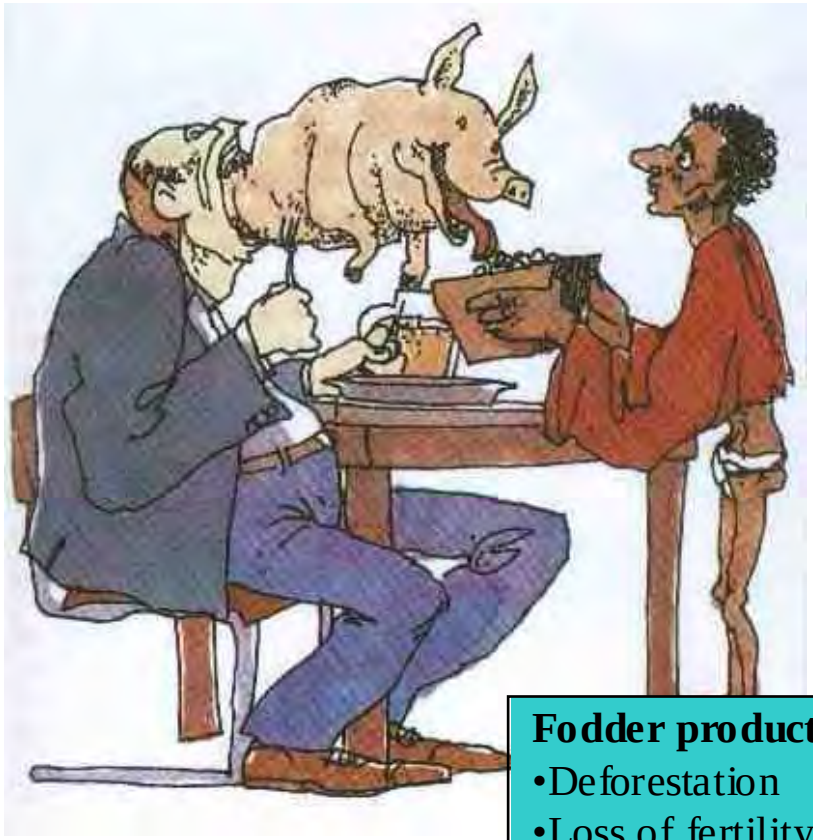
These images, from Landsats 2, 4, and 7, show the progression of deforestation in Bolivia from 1975 to 2000. This area lies east of Santa Cruz de la Sierra, Bolivia, in an area of tropical dry forest. Since the mid-1980s, the resettlement of people from the Altiplano (the Andean high plains) and a large agricultural development effort (the Tierras Baja project) has lead to this area's deforestation.

Soybean production began in earnest in the early 1970s following a substantial increase in the crop's world price. By the late 1980s, soybeans represented the country's most important oilseed crop. In 1988, soybean production amounted to about 150,000 tons. About 1/3 of the soybean harvest was used domestically in the form of soybean meal for the poultry industry. Other soybean meal was shipped to Peru and western Europe, and raw soybeans were exported via rail to Brazil.

Intensive cattle breeding is world wide problem



Intensive cattle breeding is world wide problem



Fodder production
- Deforestation
- Loss of fertility
- Erosion
- **developing countries**

Intensive cattle breeding
- Over-fertilisation
- Acidification/NHx deposition
- Veterinary problems
- **rich countries**

Since 1990 attempts to restore wetlands on agricultural lands:

Restoration measures taken:

removal of the top layer (0-20 cm) and filling in drainage ditches

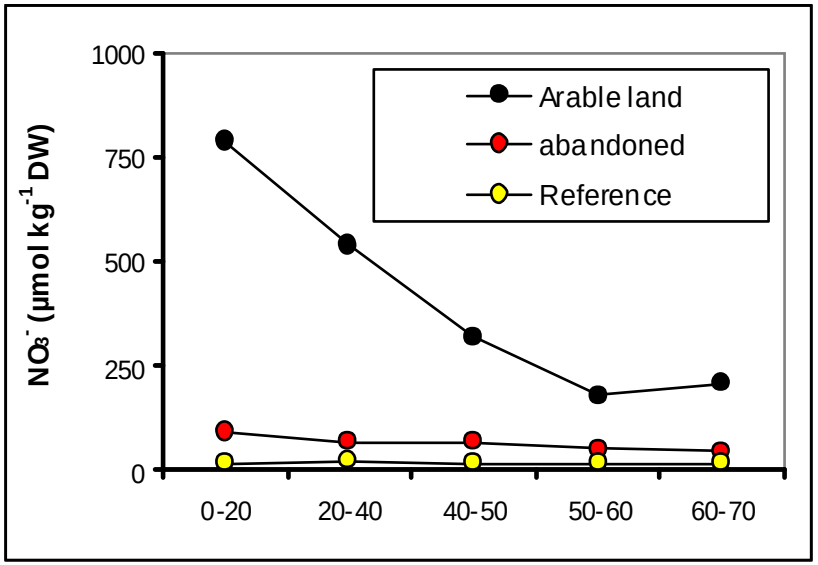
Problem: no re-development of species-rich wetlands

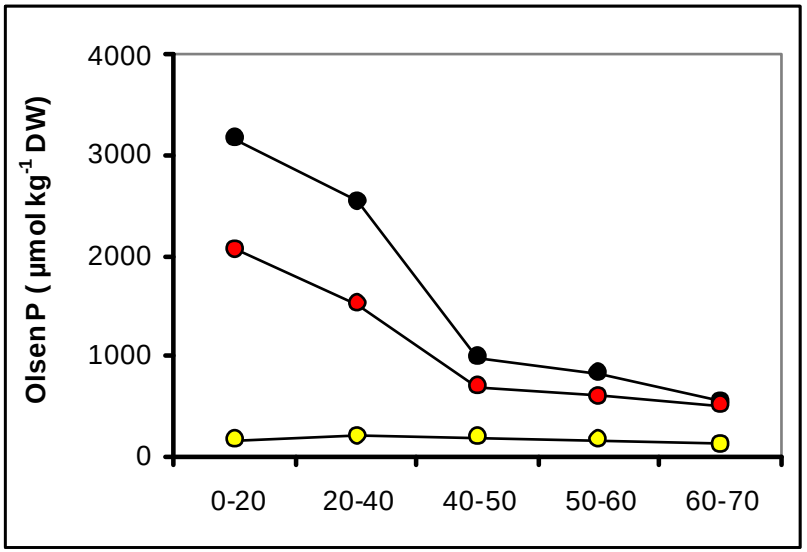
Mainly monotonous growth of *Juncus effusus* and algae

monotonous growth of *Juncus effusus*

		P(wat)	P(NaCl)	P-tot	P-Olsen	K(NaCl)	NH4(NaCl)	NO3(H2O)	pH(NaCl)	OrgMat
Reference	**Mean**	0,5	8,2	1672	164	281	143	17,6	4,2	3,3
(n=37)	**Min**	0,1	1,8	622	34	87	22	0,5	3,3	0,4
	Max	1,5	22,5	3168	320	519	500	71,9	6,1	7,1
Agricultural lands	**Mean**	132,3	89,8	17862	2806	2027	181	477	5,4	4,5
(n=39)	**Min**	2,2	19,5	5883	693	210	43	5	4,6	2,8
	Max	335,9	236,7	36498	5608	5370	383	1728	6,5	7,1

Soil profiles of agricultural lands:

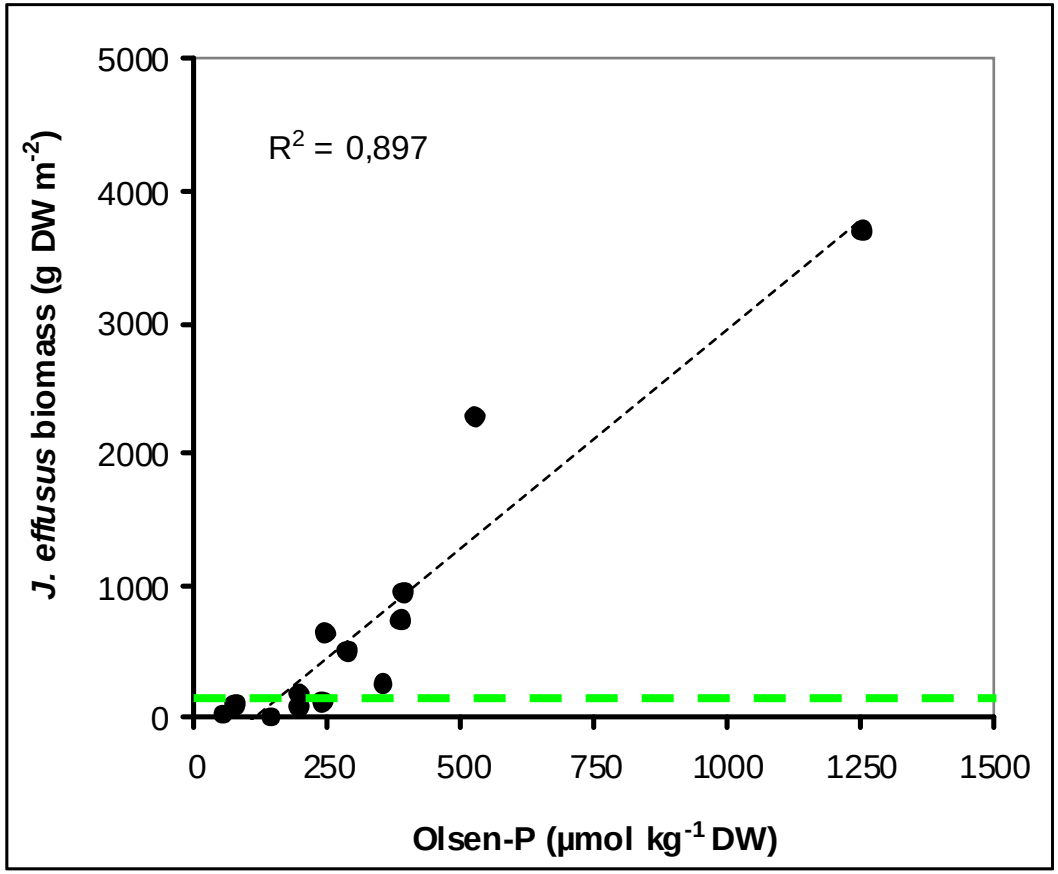




- **agricultural lands contain high N and P concentrations**
- **P is less mobile than NO_3^- and accumulates in the soil top layer**

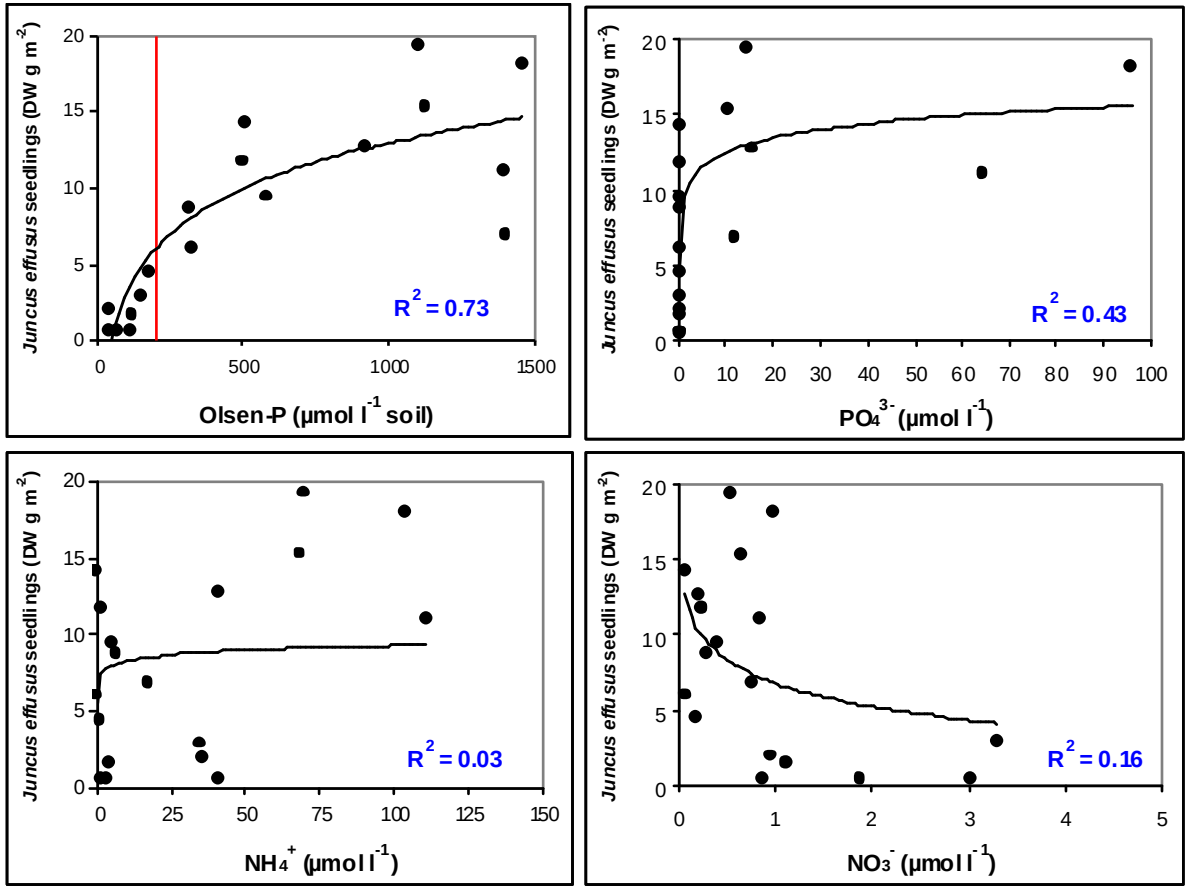
➡ **development of *J. effusus* on former agricultural lands is likely related to P !**

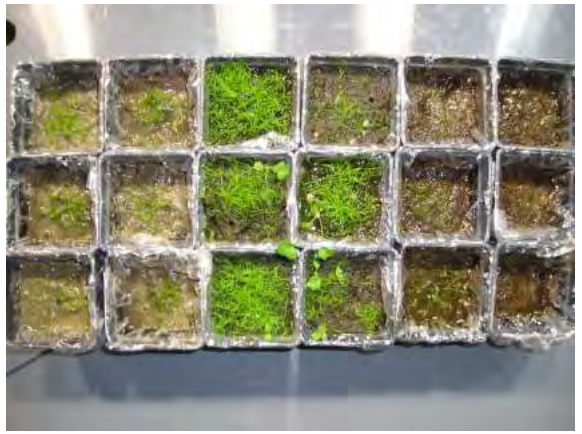
Field measurements in restored wetlands
Cover of *J. effusus* and target species related to Olsen-P ? :



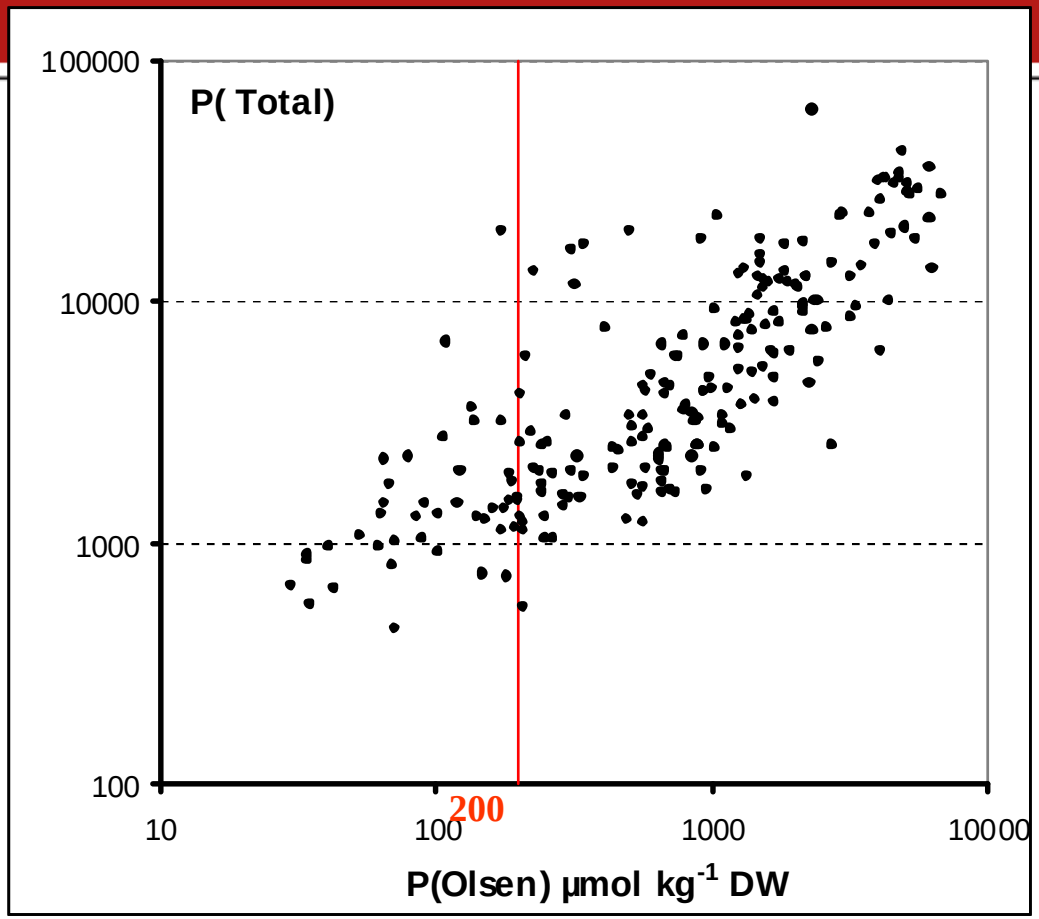
J. effusus cover is correlated with Olsen-P (Plant available P) and strongly increases above 200 µmol/kg^{-1} dry soil

Juncus effusus growth experiment:

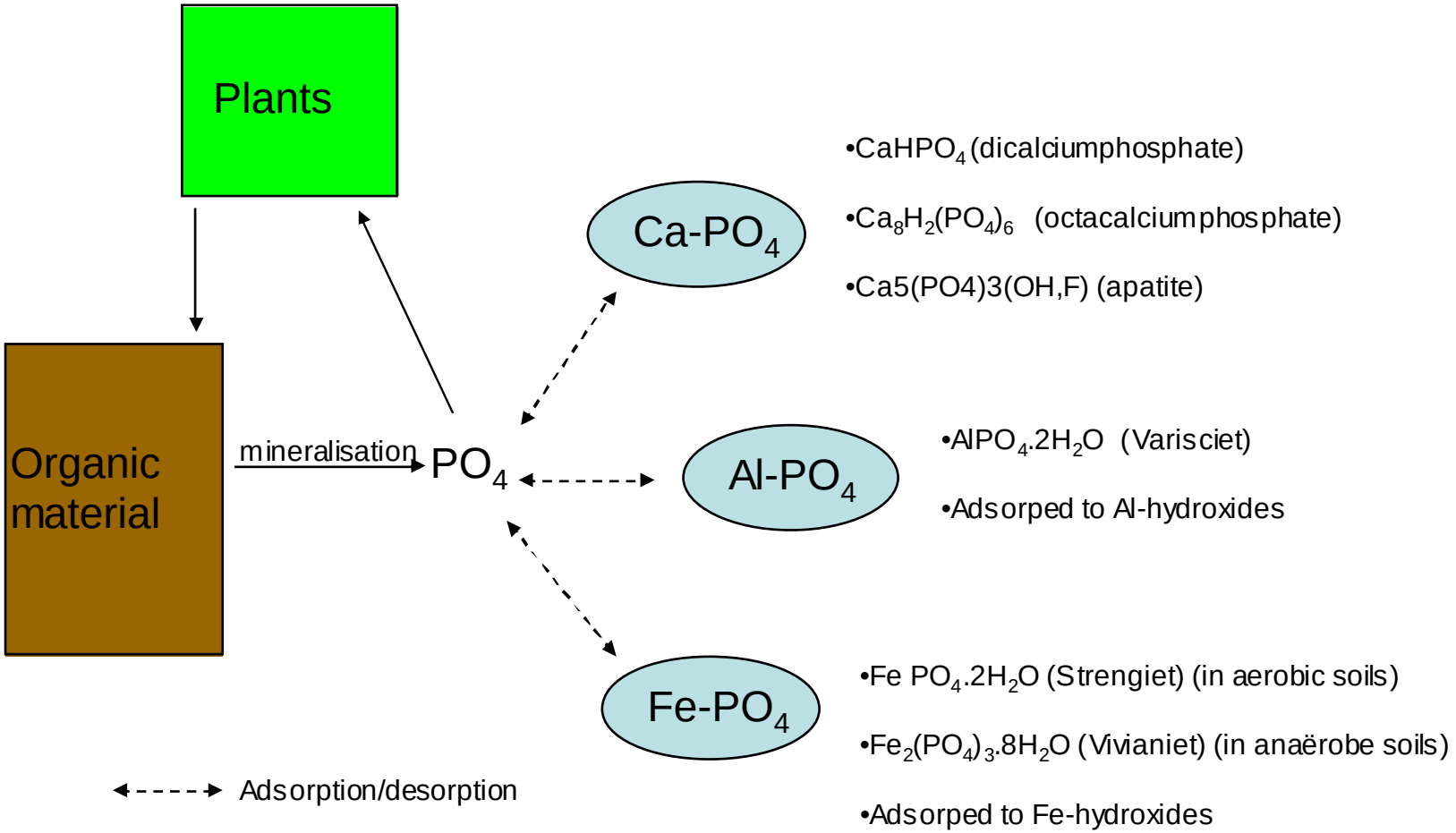


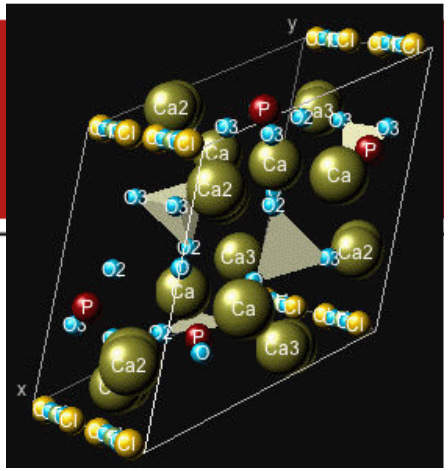


➡ **seedling development strongest correlates with Olsen-P (plant available P) and is restricted below 200 µmol/kg^{-1} dry soil**



- **Olsen-P correlates with total P but:**
- **Only a part of the total P is Olsen-P**
- **The other part exists of apatite (Ca-p), strengite (Fe-P) and organic bound-P**


Plants
Organic material
mineralisation
PO_4
Ca-PO_4
Al-PO_4
Fe-PO_4
•$CaHPO_4$ (dicalciumphosphate)
•$Ca_8H_2(PO_4)_6$ (octacalciumphosphate)
•Ca5(PO4)3(OH,F) (apatite)
•$AlPO_4.2H_2O$ (Varisciet)
•Adsorped to Al-hydroxides
•Fe $PO_4.2H_2O$ (Strengiet) (in aerobic soils)
•$Fe_2(PO_4)_3.8H_2O$ (Vivianiet) (in anaërobe soils)
•Adsorped to Fe-hydroxides
Adsorption/desorption

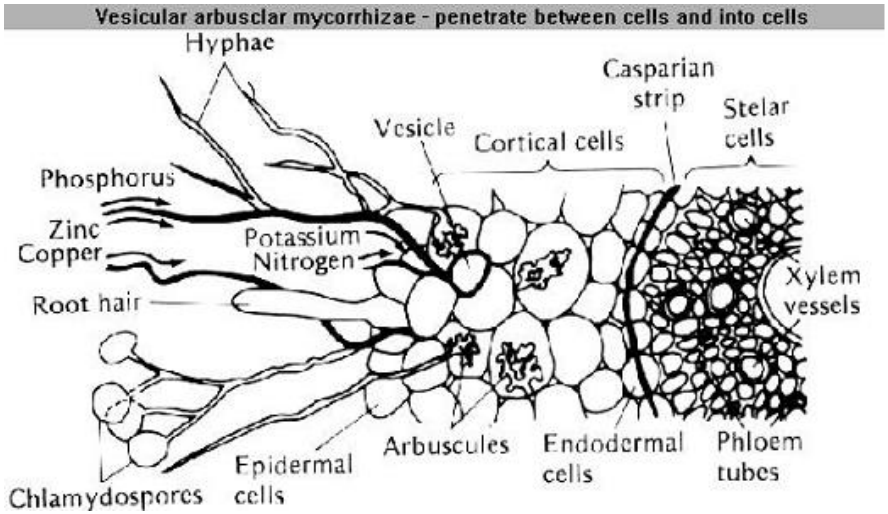


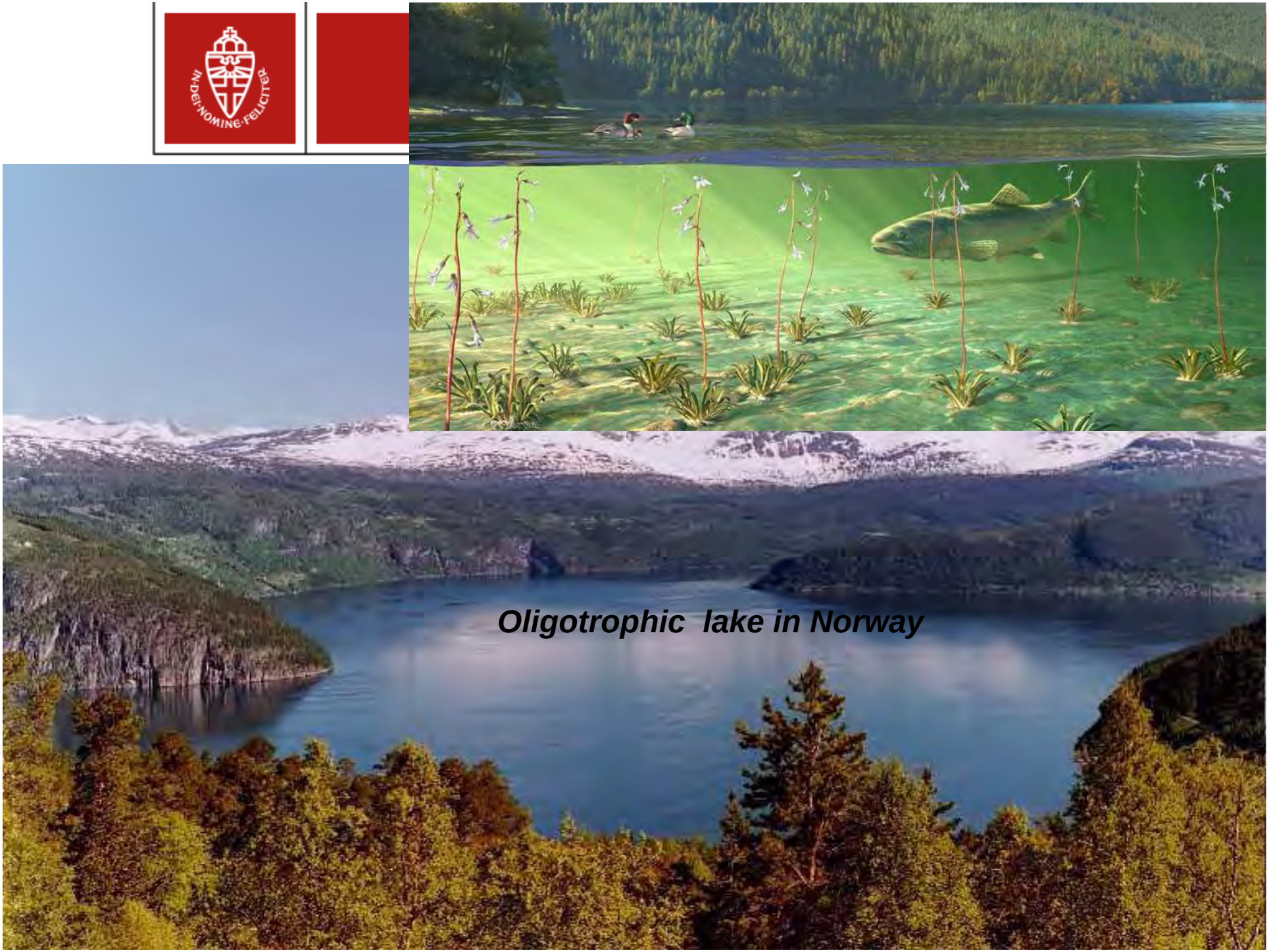
Phosphorus

In soil and sediments phosphorus can be found as insoluble rock-phosphate (apatite)

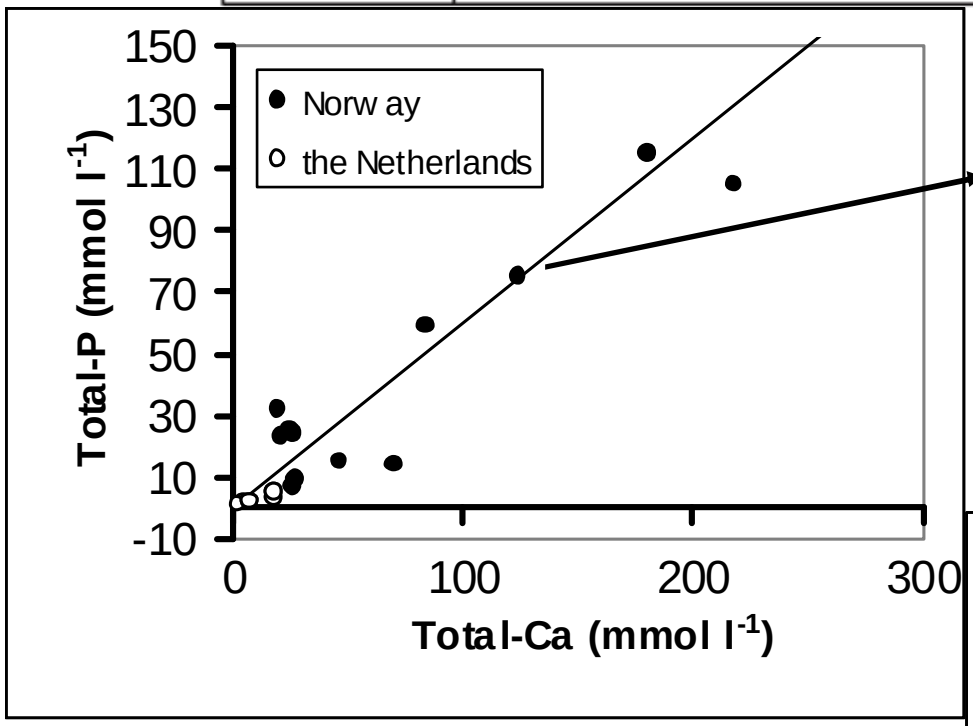
- Hydroxyapatite → $Ca_5(PO4)_3(OH)$
- Fluorapatite → $Ca_5(PO4)_3F$

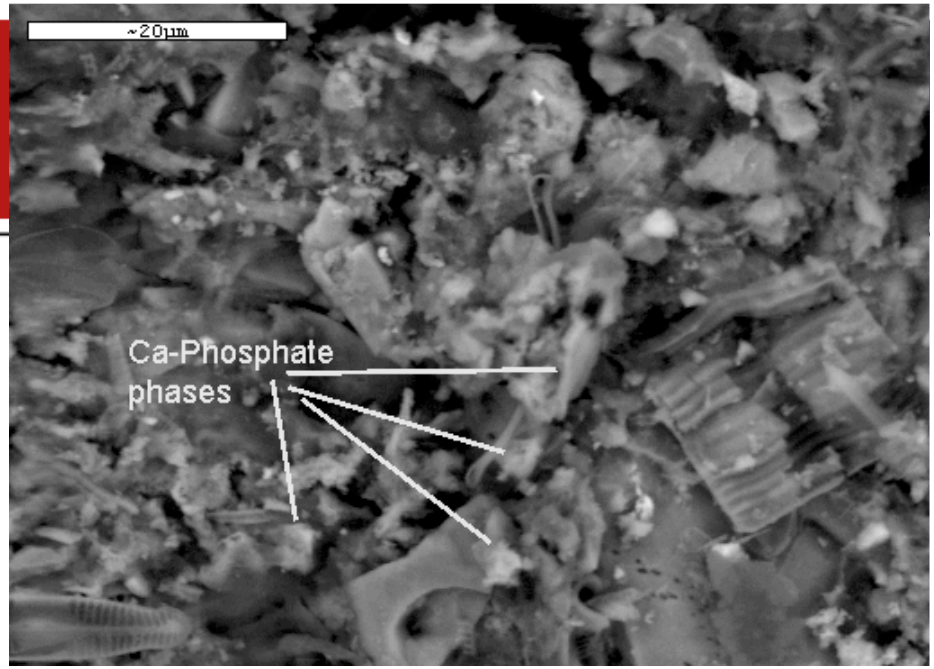
- Higher plants can take up phosphorus from apatite by means of mycorrhiza's.

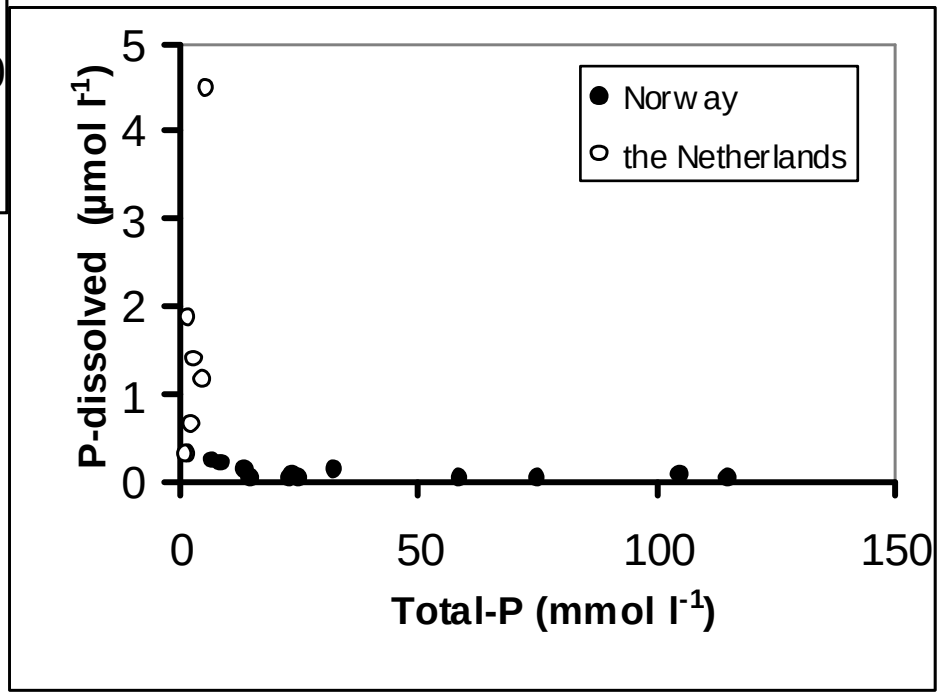


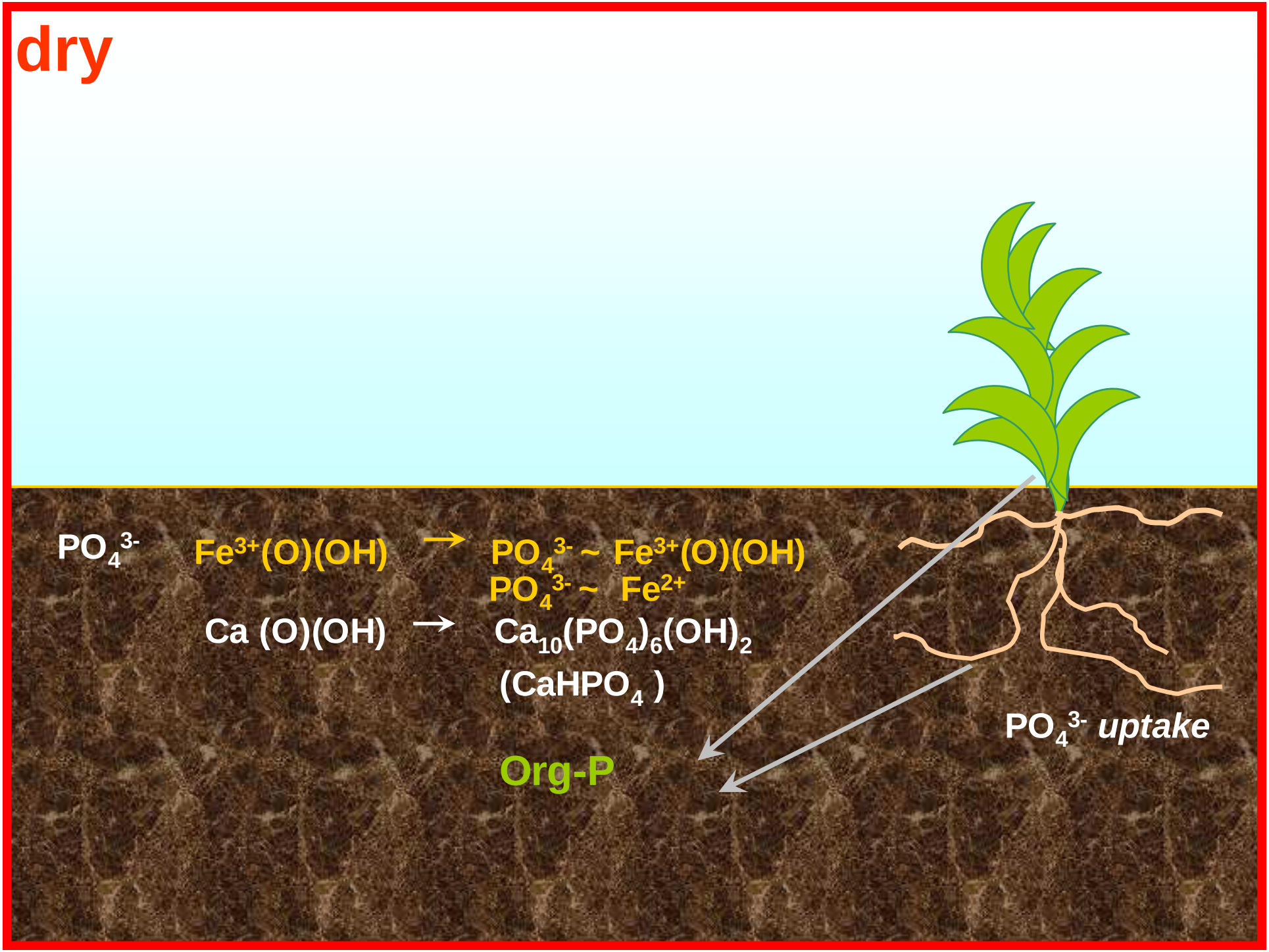


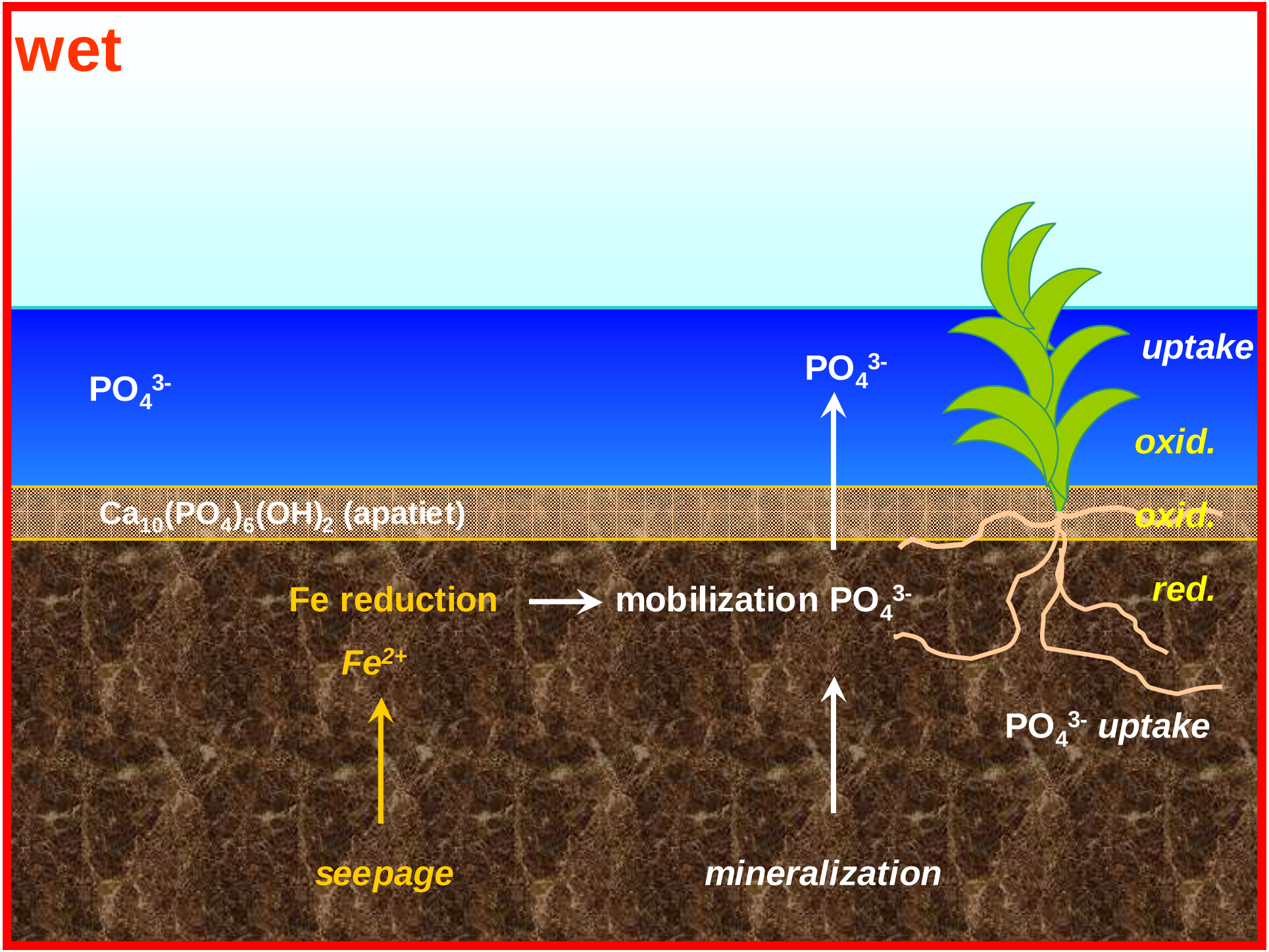
Oligotrophic lake in Norway


Norway
the Netherlands
Total-P (mmol l-1)
Total-Ca (mmol l-1)
150
130
110
90
70
50
30
10
-10
0
100
200
300

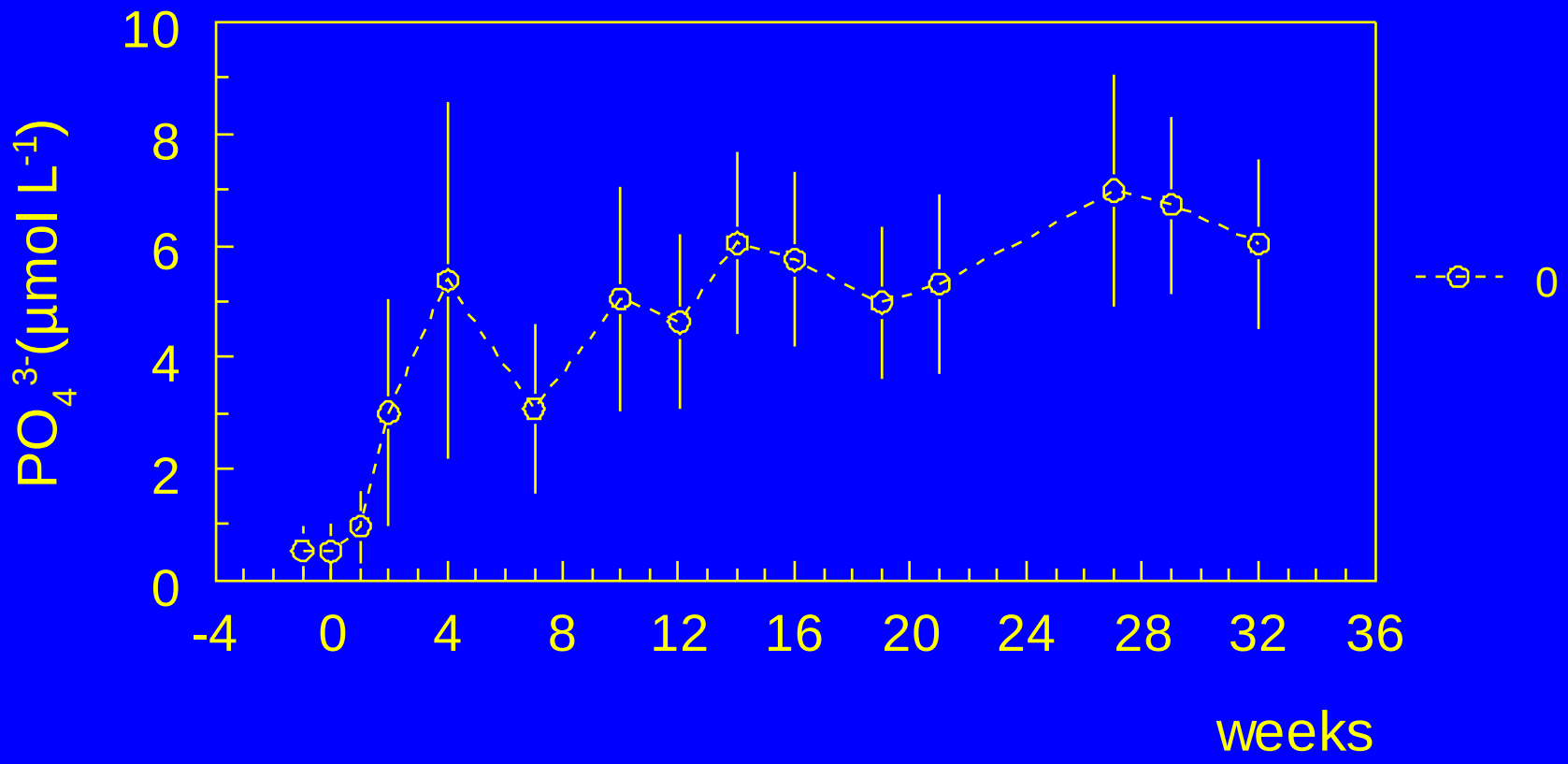

~20µm
Ca-Phosphate
phases

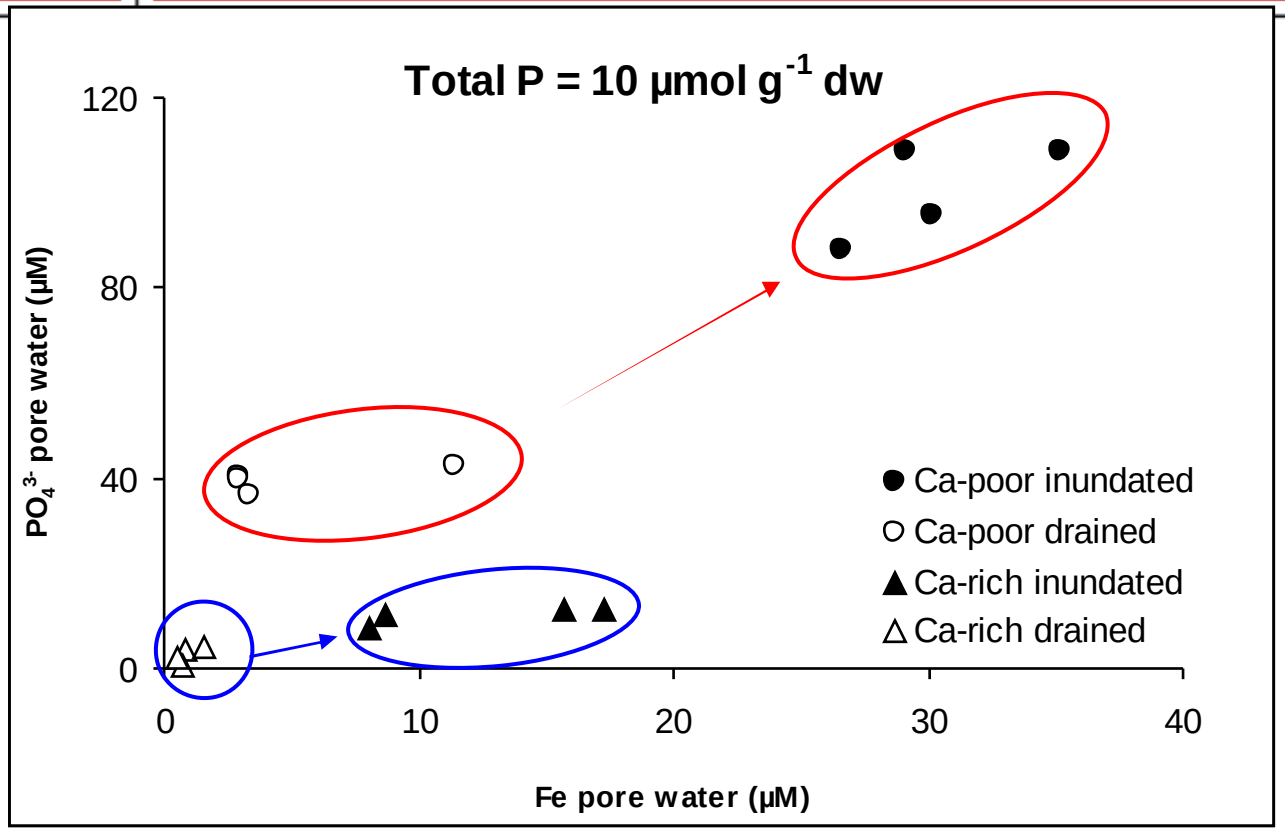

Norway
the Netherlands
P-dissolved (µmol l-1)
Total-P (mmol l-1)
5
4
3
2
1
0
0
50
100
150


dry
PO_4^{3-}
$Fe^{3+}(O)(OH)$ → $PO_4^{3-} \sim Fe^{3+}(O)(OH)$
$PO_4^{3-} \sim Fe^{2+}$
Ca (O)(OH) → $Ca_{10}(PO_4)_6(OH)_2$
($CaHPO_4$)
Org-P
PO_4^{3-} *uptake*


wet
PO_4^{3-}
PO_4^{3-}
uptake
oxid.
$Ca_{10}(PO_4)_6(OH)_2$ (apatiet)
oxid.
red.
Fe reduction
mobilization PO_4^{3-}
Fe^{2+}
PO_4^{3-} uptake
seepage
mineralization

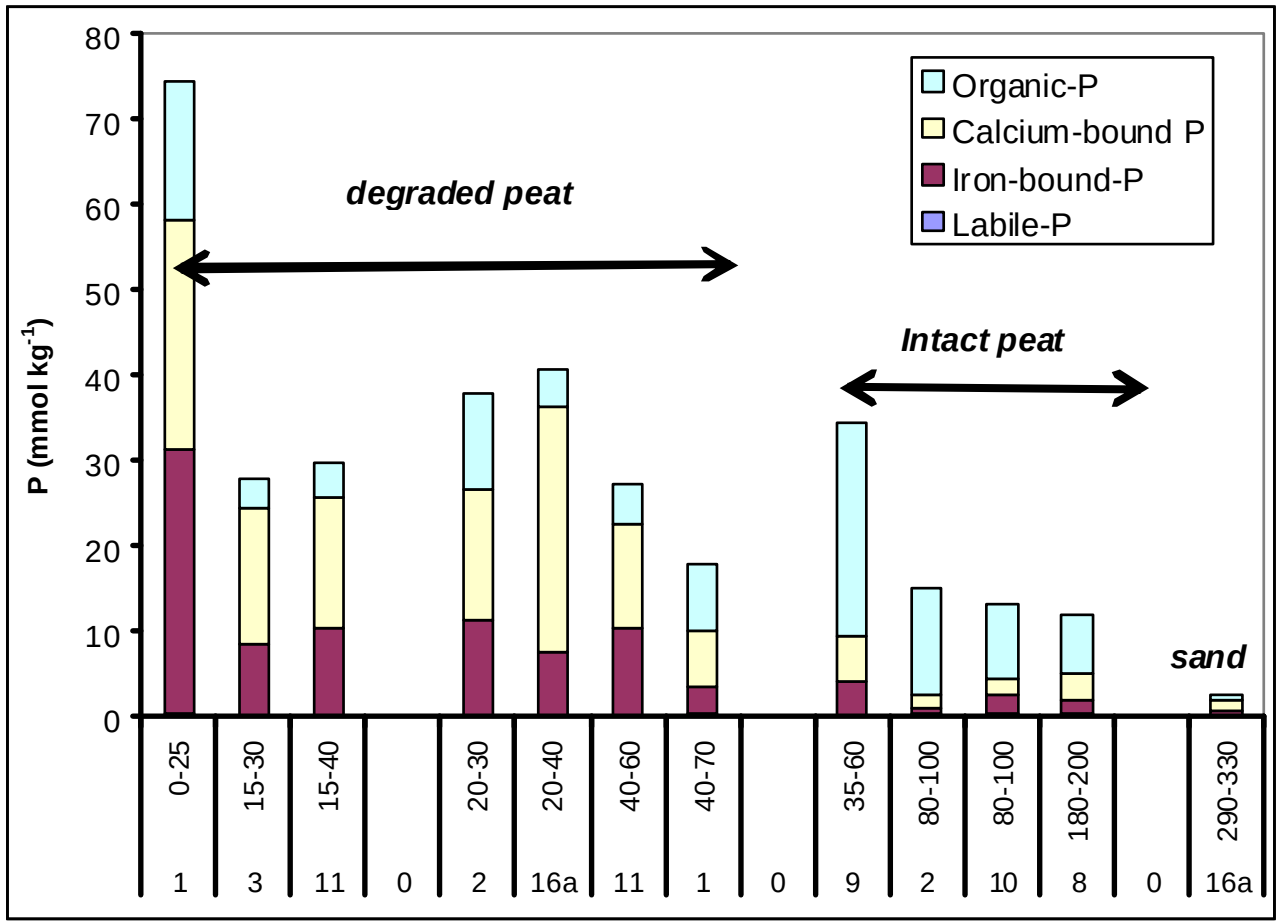
Rewetting of grassland



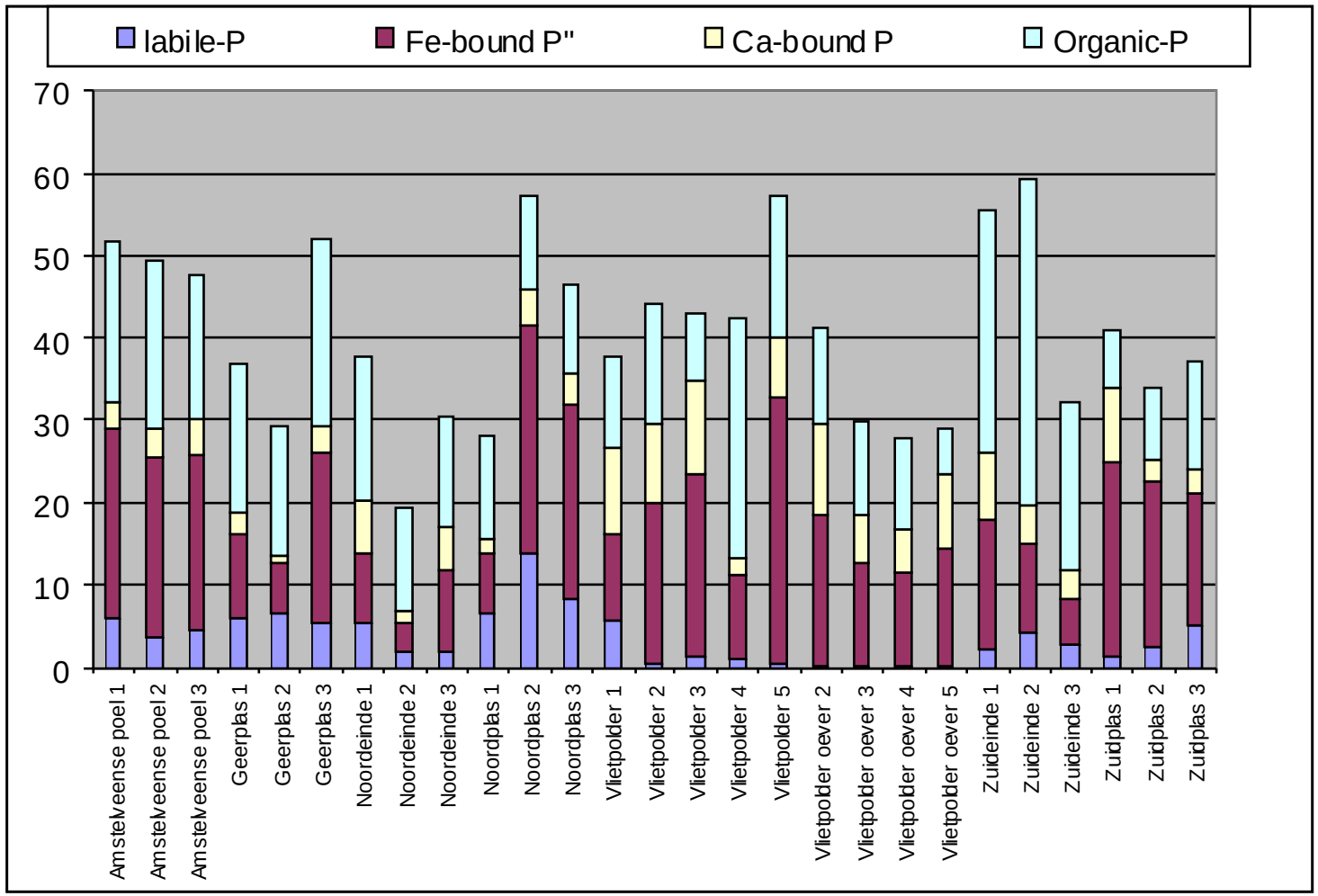


- **Ca-P strongly binds P and is not sensitive to redox reactions**
- **Fe-P is sensitive to inundation which can lead to P mobilisation and eutrophication of the water layer**
- **This can also be the case when Olsen-P is < 200 µmol g^{-1} dw !!!**

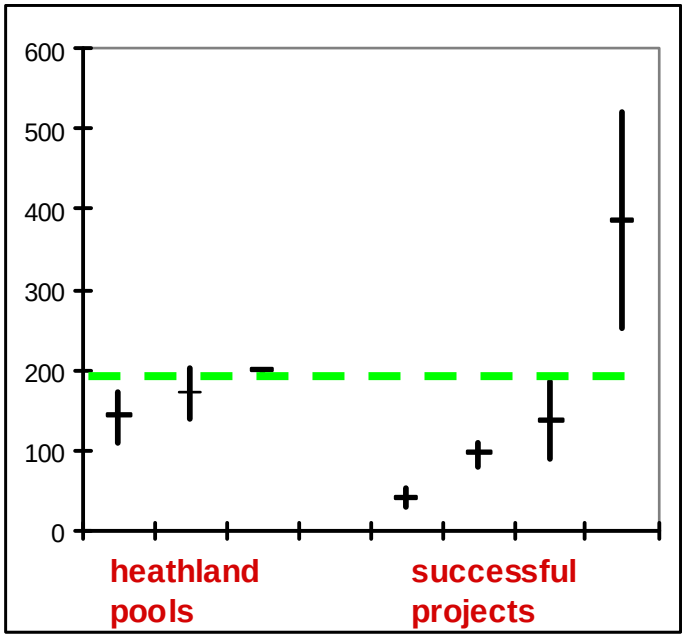
Fractionation of sediment phosphate with chelating compounds

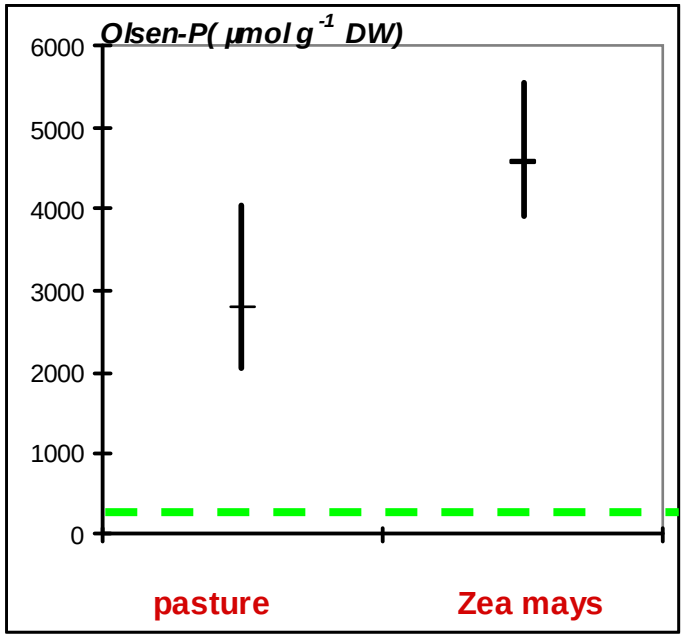


Fractionation of sediment phosphate with chelating compounds



Olsen-P in top layer of various ecosystems:





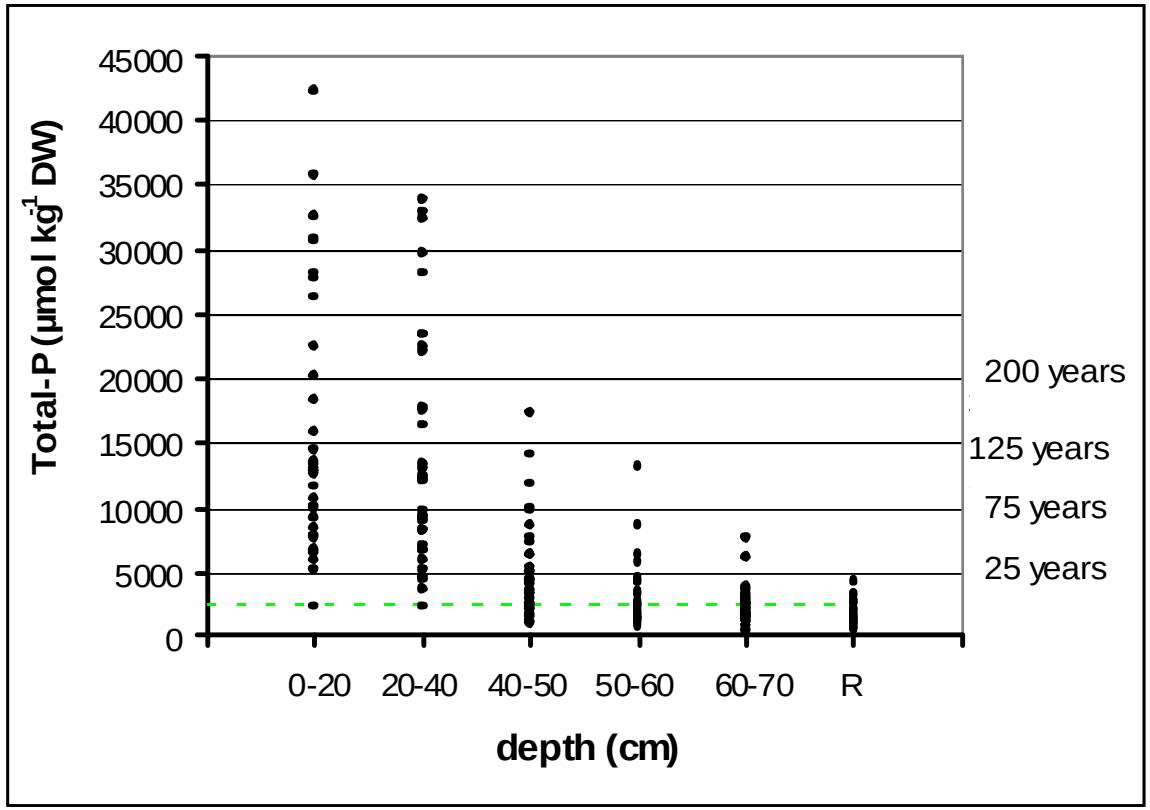
- Olsen-P < 200 µmol g^{-1} dry soil in species-rich wetlands
- Olsen-P very high on agricultural lands

➡ So just filling in drainage ditches will always lead to massive *J. effusus* development

1) Mowing and removing hay?

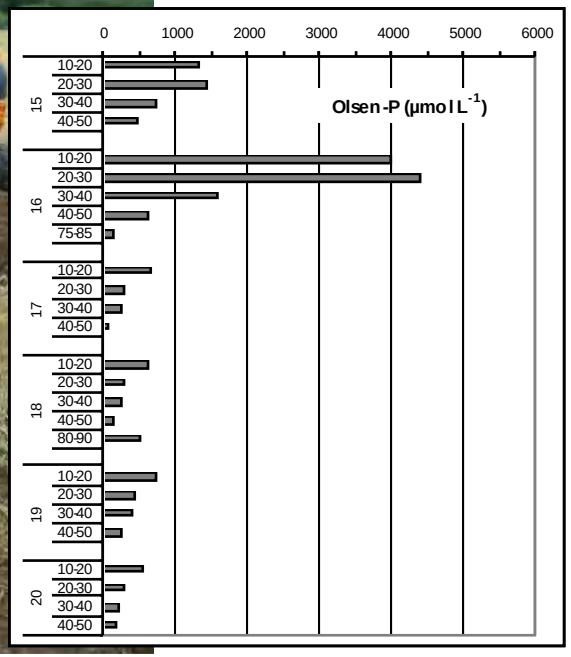
Additional restoration measures

1) Mowing and removing ?



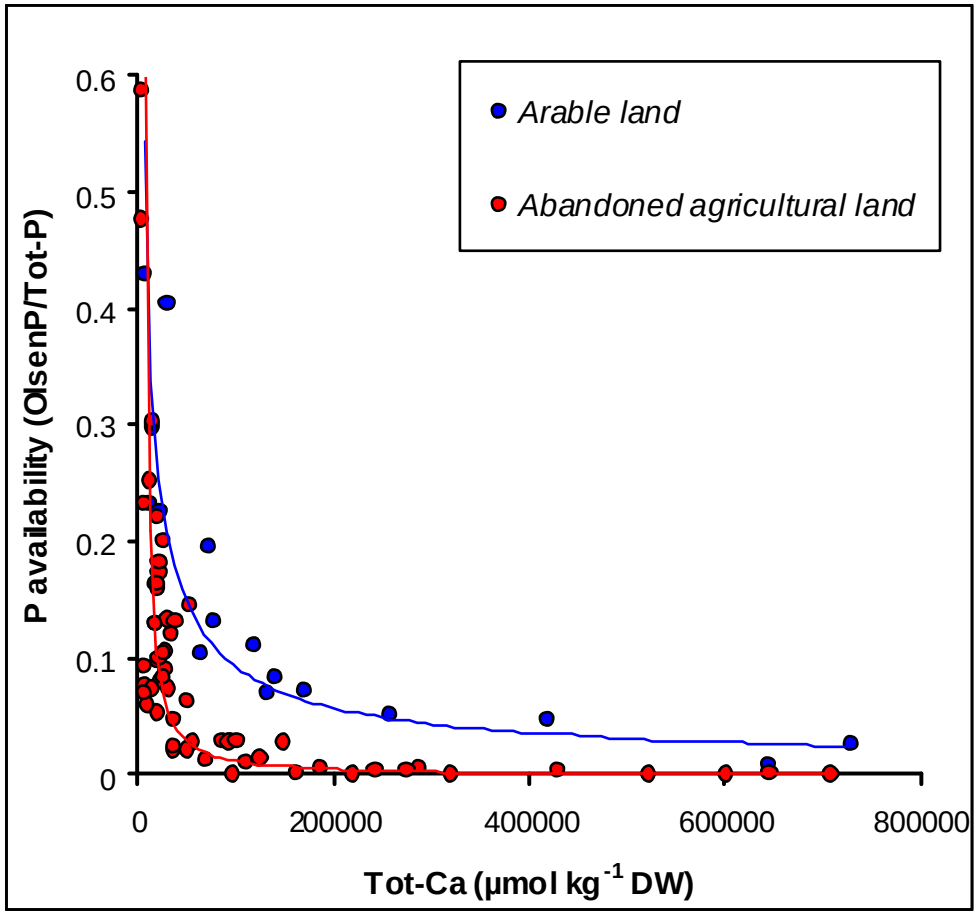
➡ **Mowing and removing takes hundred years**

2) Top soil removal after studying required removal depth?



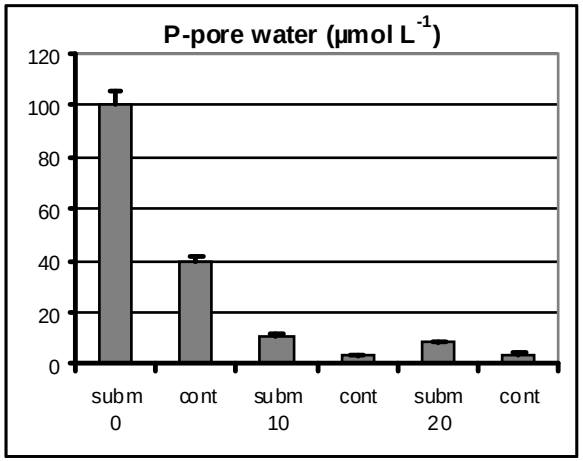
3) P-immobilisation by lime addition ?

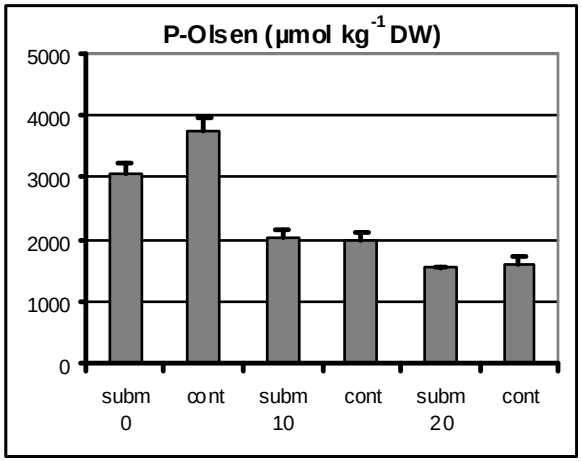
Re-creation of wetlands on former agricultural lands

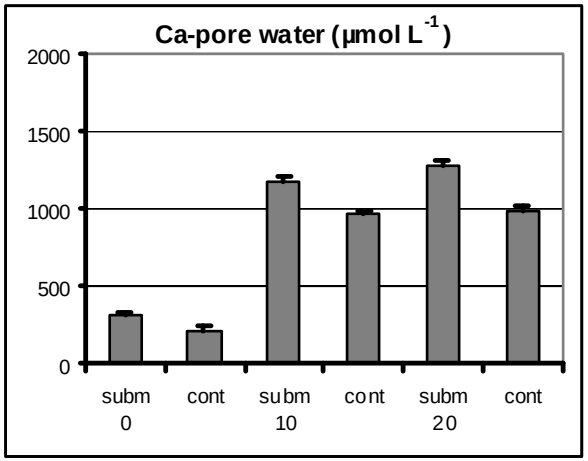


- **Ca-rich soils contain low Olsen-P due to Ca-P complex formation**
- **Olsen-P availability only strongly decreases in abandoned soils rich in Ca**

Laboratory growth experiment:

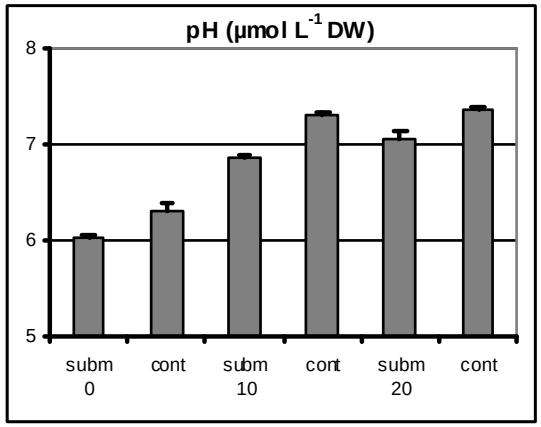


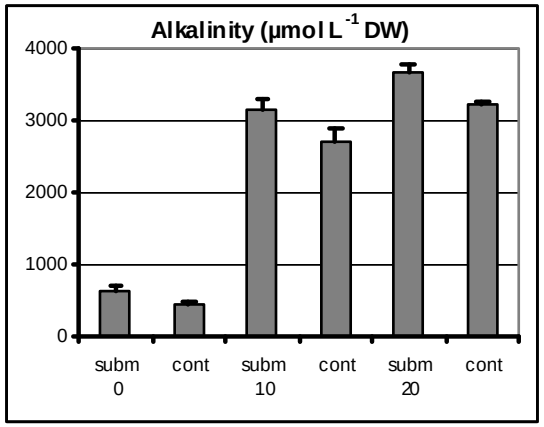


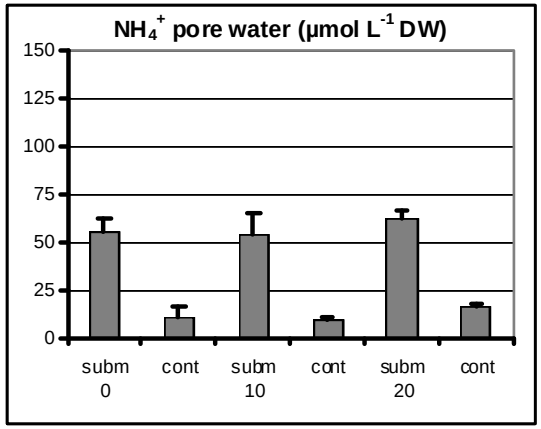


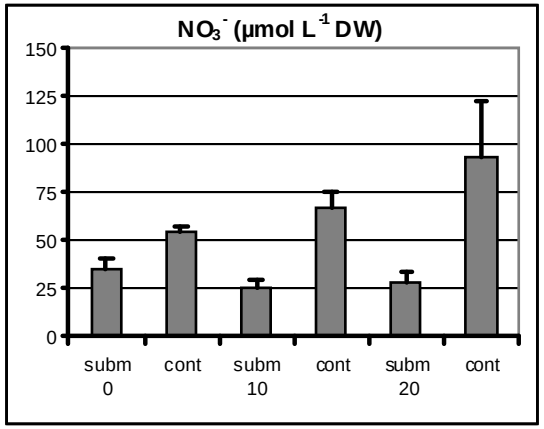
J. effusus **growth is inhibited at deep soil layers with low Olsen-P content**

Laboratory growth experiment:









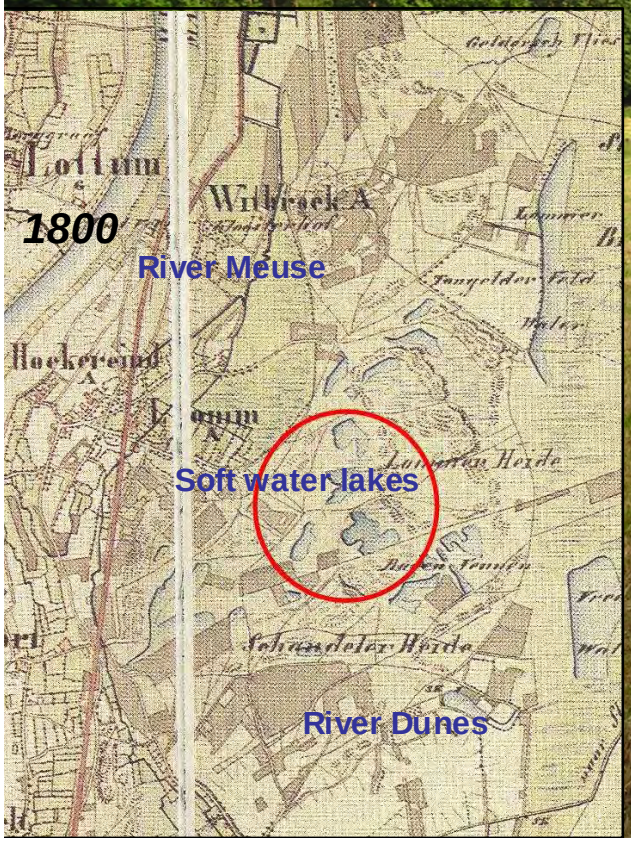
- **Lime addition strongly immobilises P in the water layer**
- **Lime addition reduces Olsen-P in the soil to some extent**
- **Liming can be an additional restoration in combination with soil removal**

Conclusion

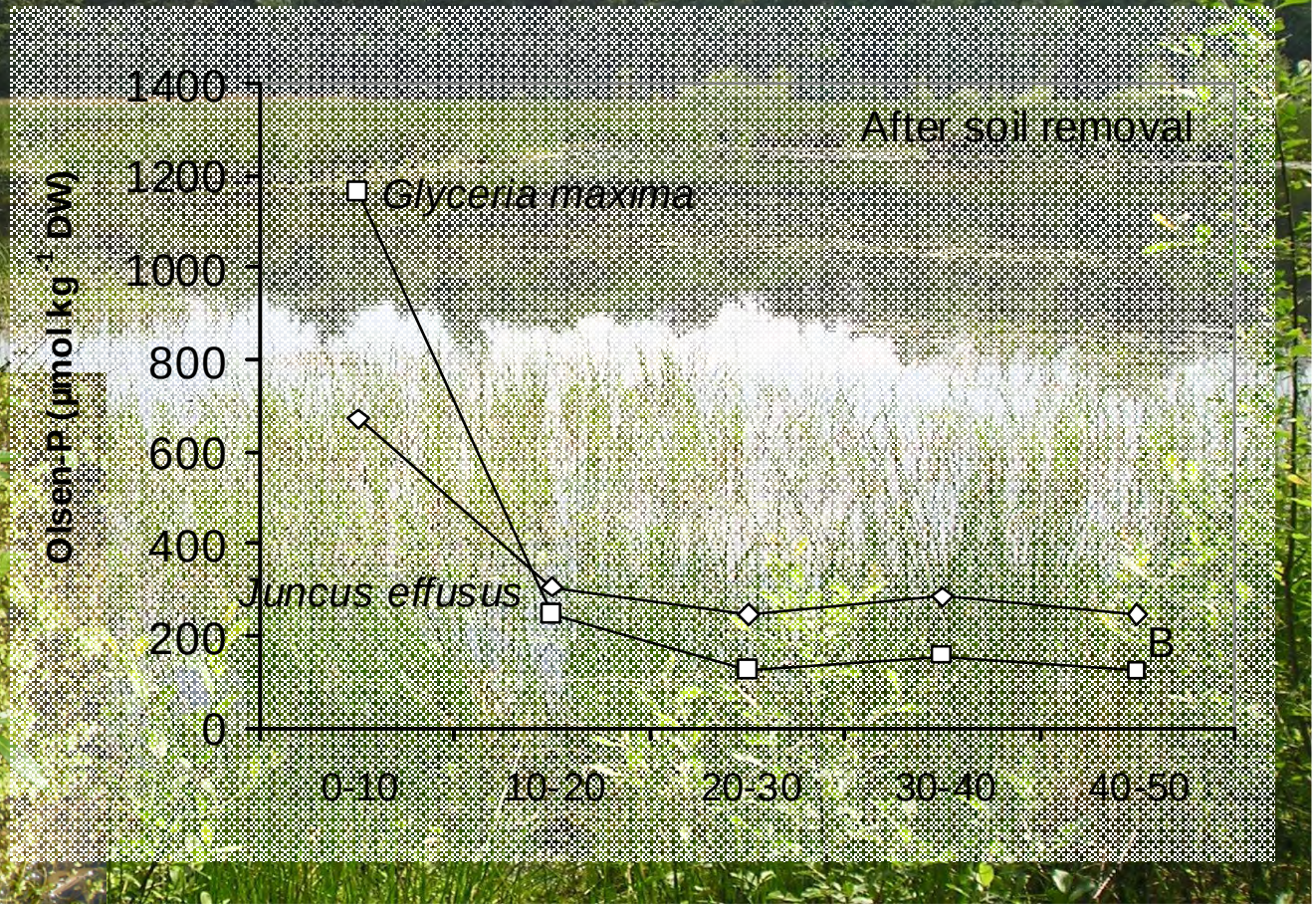
Simply filling in drainage ditches in combination with top layer removal (0-10 cm) leads to P eutrophication and development of turbid waters with dominant growth of *Juncus effusus* on former Ca-poor agricultural lands.

Removal of the P saturated soil layer (200 µmol g dw-1) (*in combination with *immobilisation of P by the addition of lime) is necessary for successful restoration

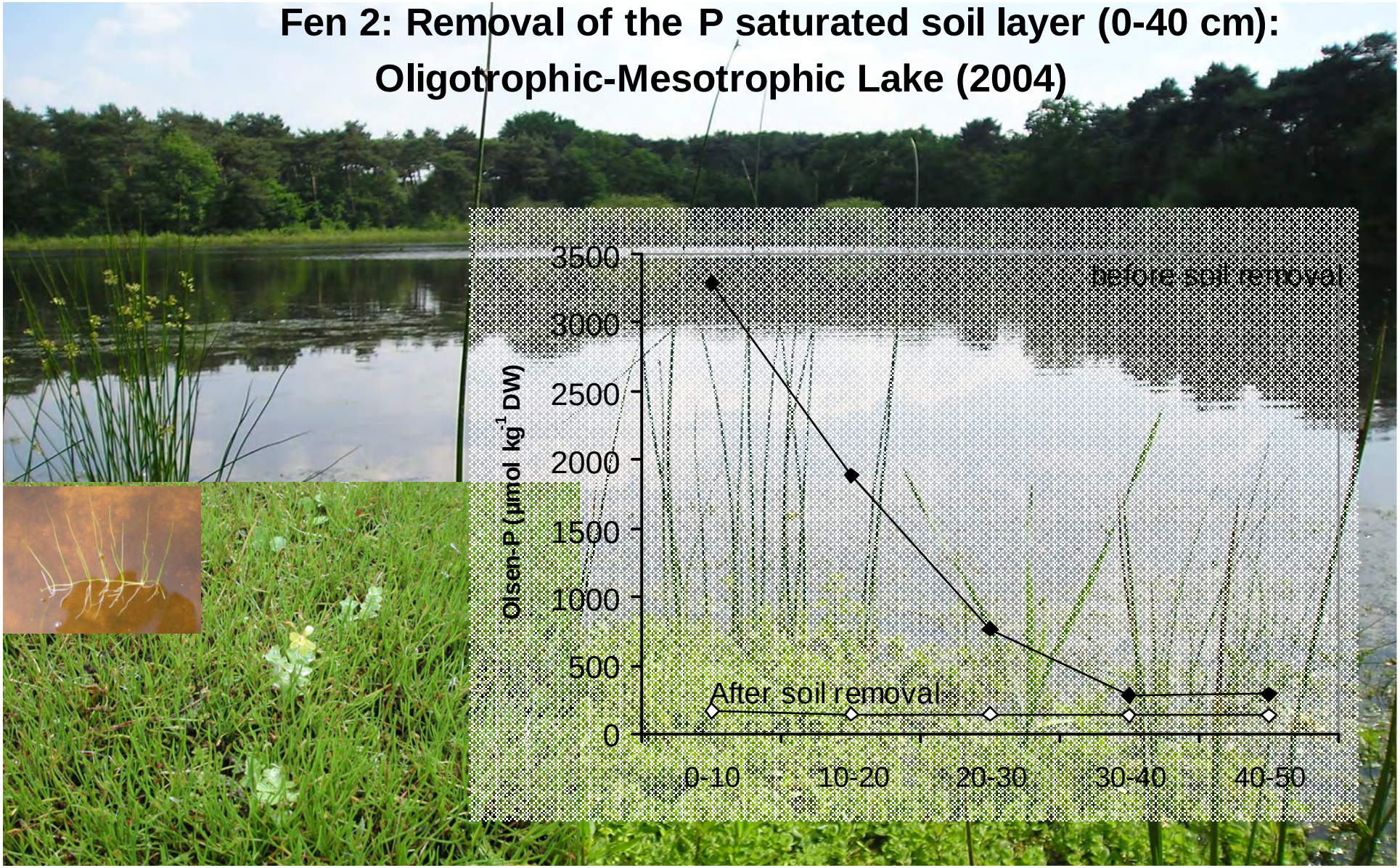
Example: restoration of the Ravenvennen (1997):



Fen 1: Removal of the soil top layer (0-20 cm): Eutrophic Lake (2005)



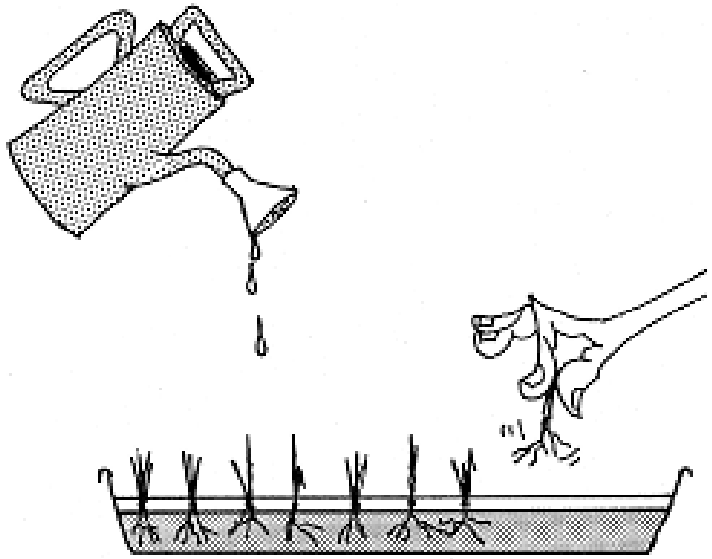
Fen 2: Removal of the P saturated soil layer (0-40 cm): Oligotrophic-Mesotrophic Lake (2004)

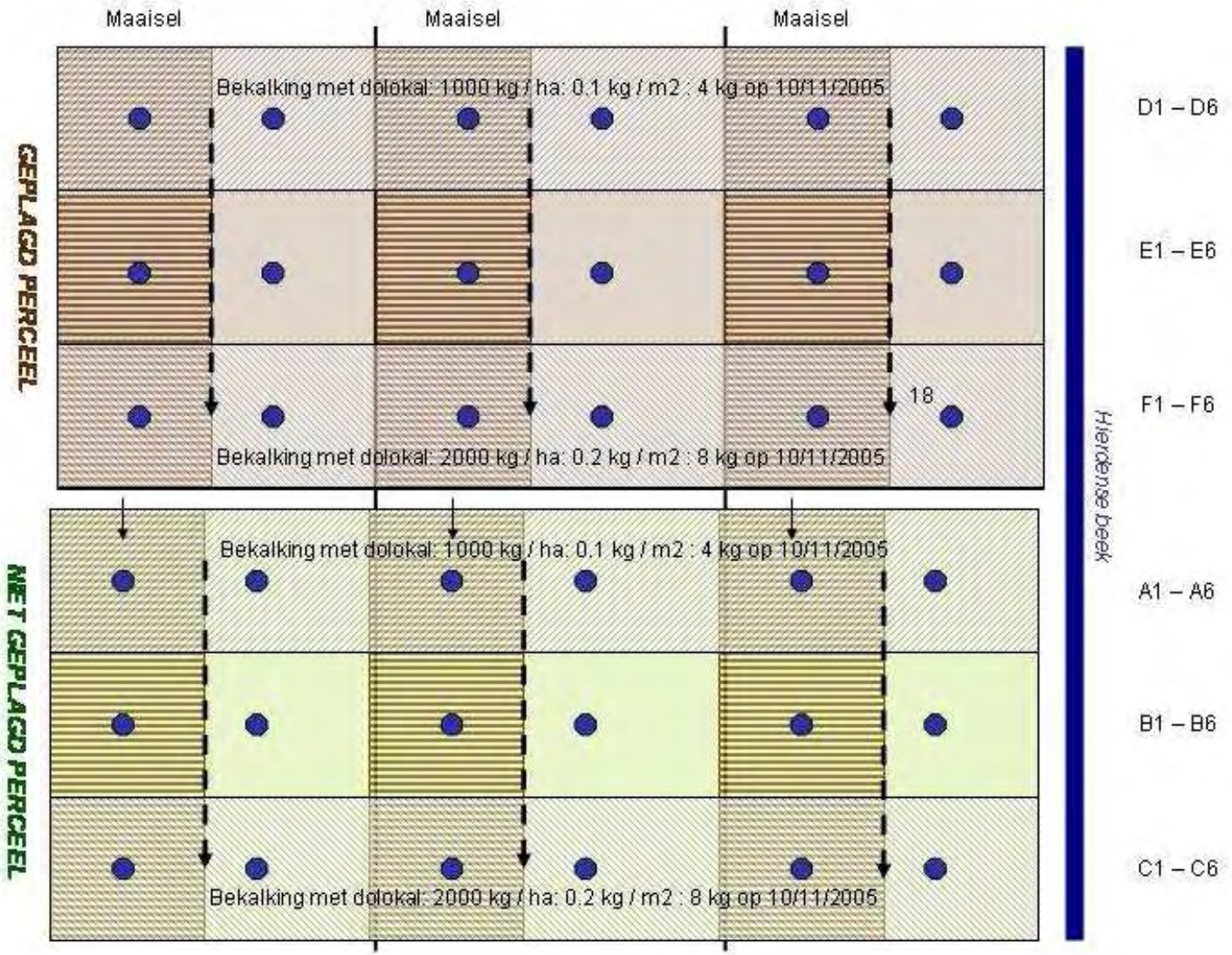


Research on the natural seed-bank may be important

Beal (started in 1879, 1st published in 1911), Michigan State University buried seed of 21 common plant species (50 seed each) with sand in 20 glass bottles. 15th bottle was exhumed in 2000 (120 years after burial) and 2 of the species germinated

1920, 8 species germinated
1940, 3 species germinated
1980, 2 species germinated




Maaisel
Maaisel
Maaisel
Bekalking met dolokal: 1000 kg / ha: 0.1 kg / m2 : 4 kg op 10/11/2005
GEPLAGD PERCEEL
18
Bekalking met dolokal: 2000 kg / ha: 0.2 kg / m2 : 8 kg op 10/11/2005
Bekalking met dolokal: 1000 kg / ha: 0.1 kg / m2 : 4 kg op 10/11/2005
NIET GEPLAGD PERCEEL
Bekalking met dolokal: 2000 kg / ha: 0.2 kg / m2 : 8 kg op 10/11/2005
D1 – D6
E1 – E6
F1 – F6
Hierdense beek
A1 – A6
B1 – B6
C1 – C6

Experimental set up

Top soil removal (30 cm)

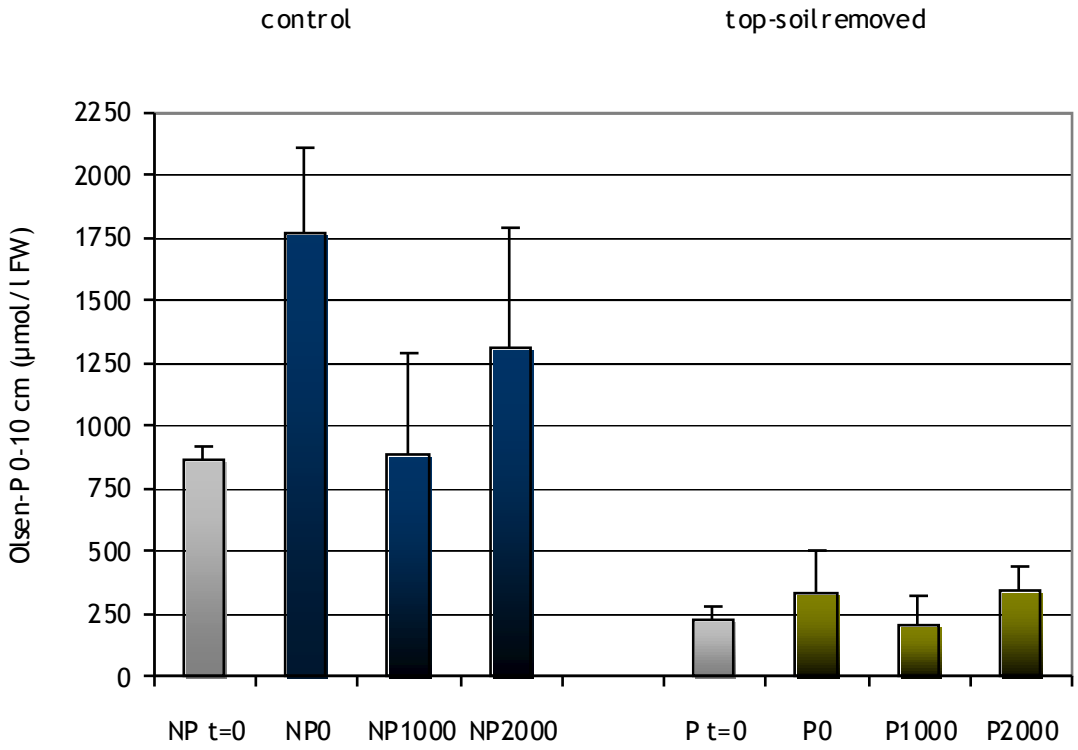
Top soil removed

Liming

Introduction of hay

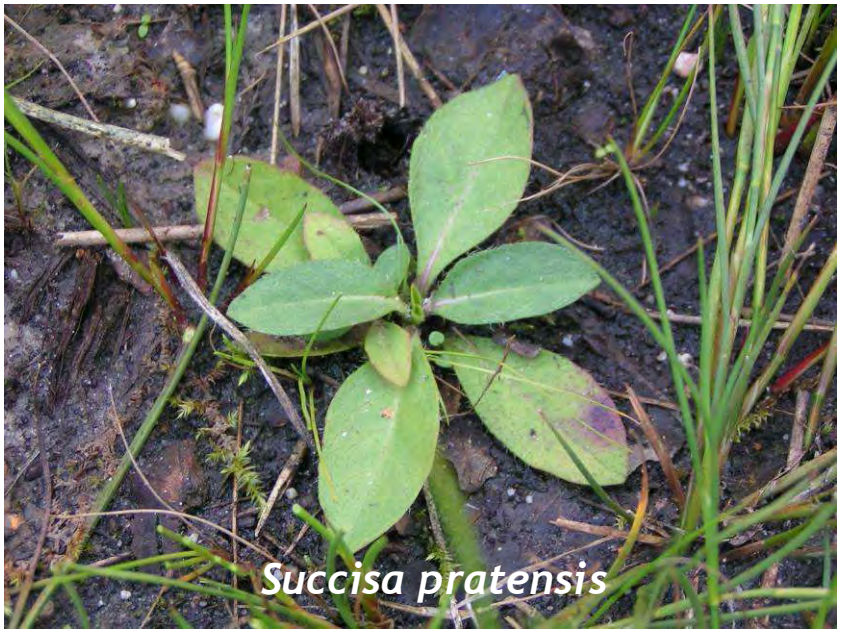
BIOGEOCHEMICAL WATER-MANAGEMENT & APPLIED RESEARCH ON ECOSYSTEMS

Soil chemistry: Olsen-P



Vegetation

Mean species richness	liming						Total
	no		1000 kg/ha		2000 kg/ha		
	Introduction of hay	No hay	Introduction of hay	No hay	Introduction of hay	No hay	
Control plots	10	10	10	10	11	11	35
Sod-cutted plots	32 (7)	19 (1)	35 (4)	23	30 (7)	18	89



Target species

Succisa pratensis

Gentiana pneunomonanthe

Pedicularis sylvatica

Drosera intermedia

Drosera rotundifolia

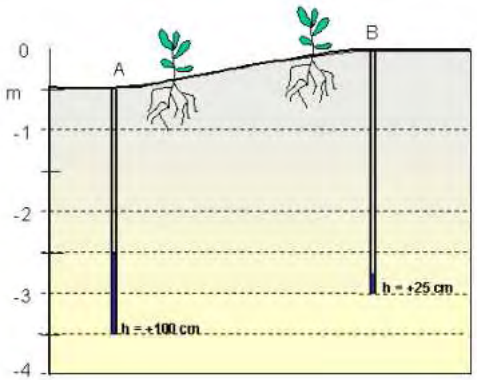
Rhynchospera alba

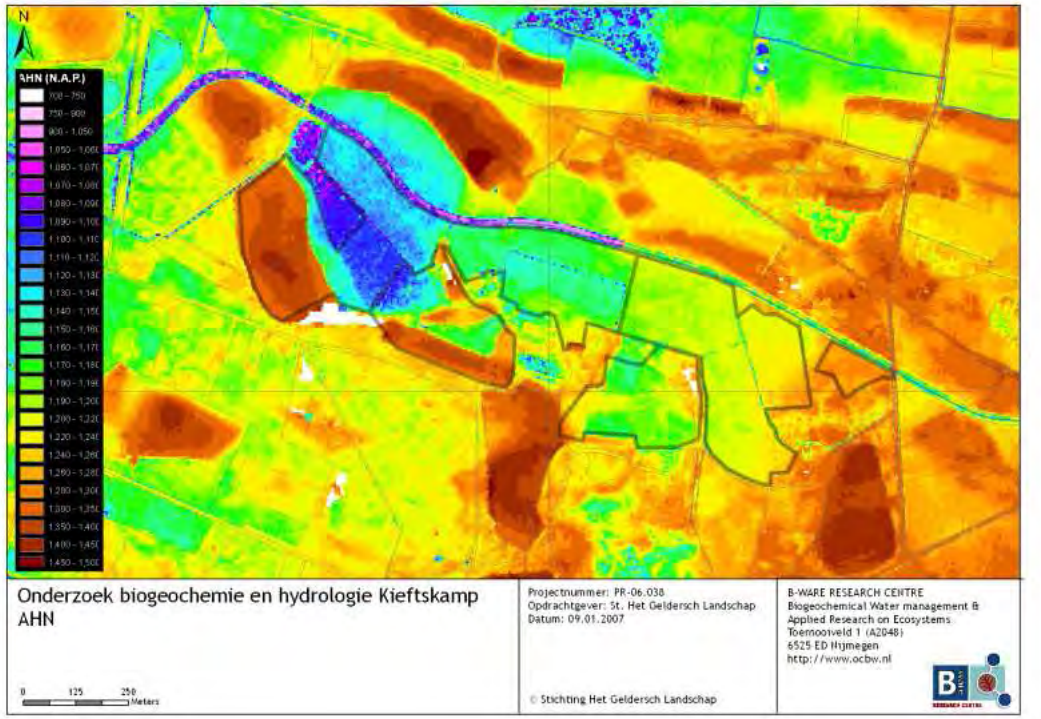
Narthecium ossifragum

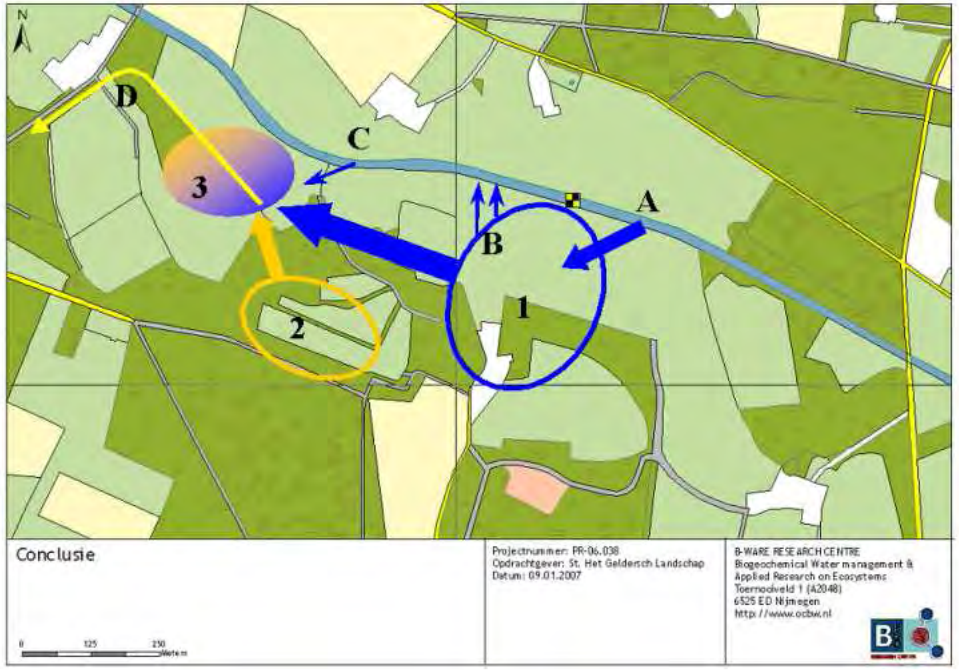
Euphrasia stricta

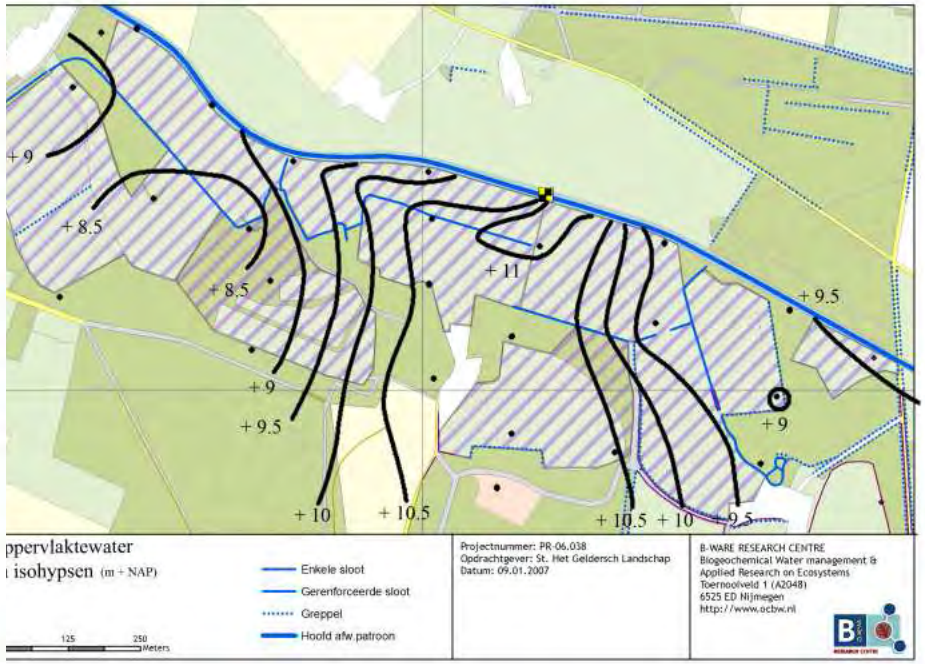
Parnassia palustris

Hydrology is also important

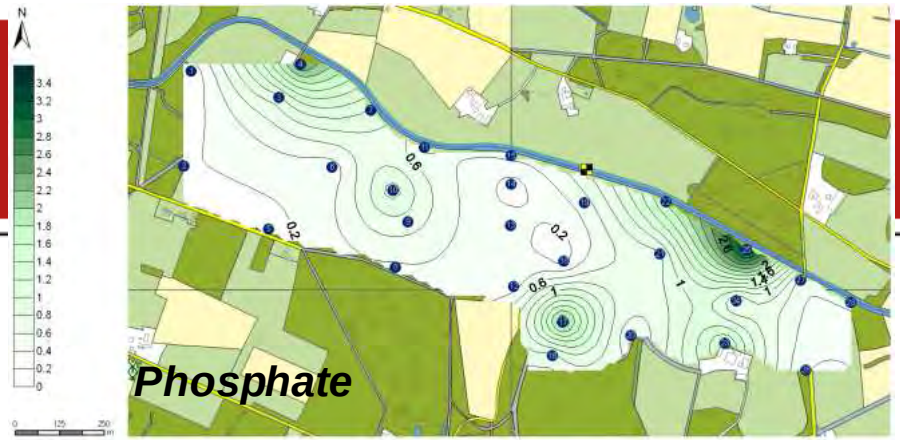








Just as hydrochemistry



Figuur 6.6: Fosfaat in het grondwater

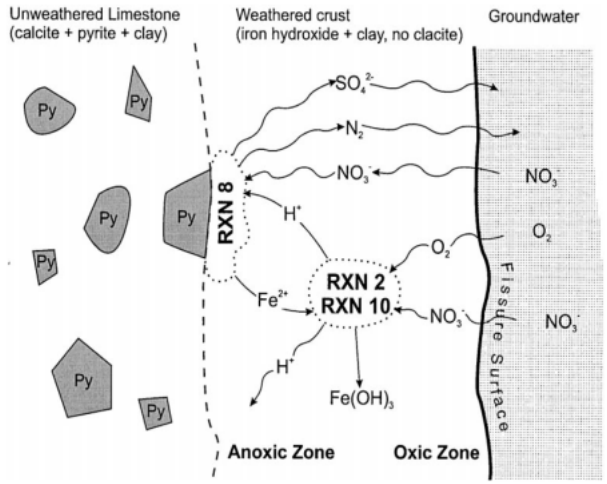
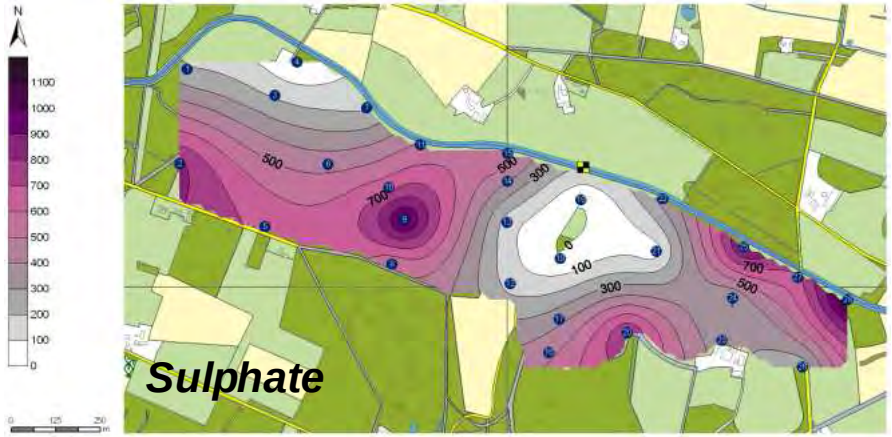
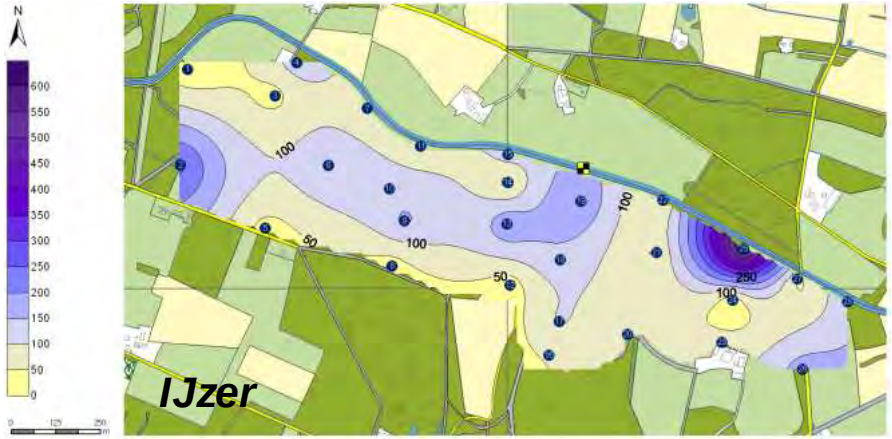


Fig. 5. Conceptual chemical model for the coupled reduction of nitrate and oxygen on fissure surfaces in the shallow confined zone using pyrite as an electron donor.

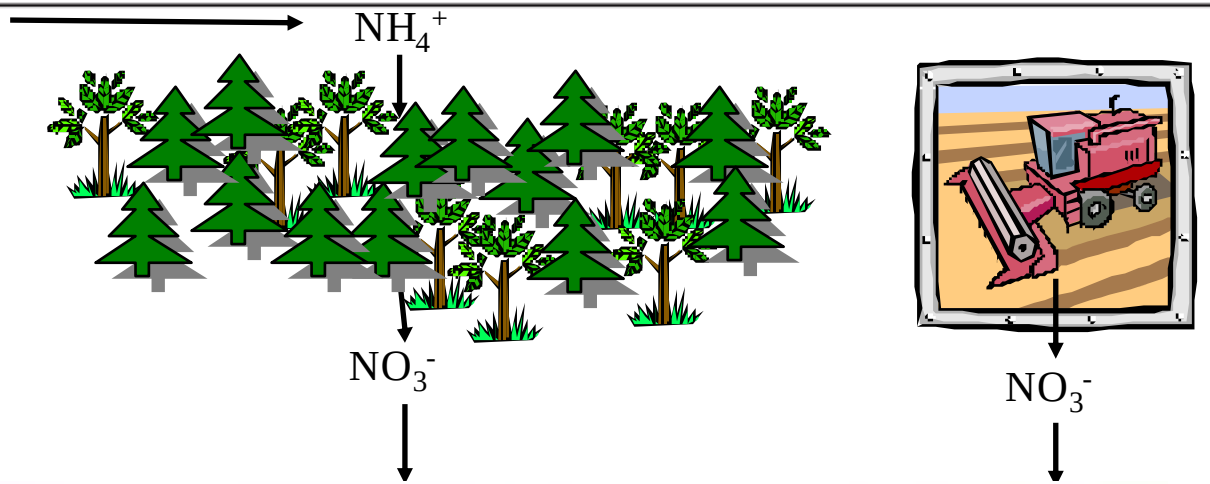


Figuur 6.7: Zwavelgehalte in het grondwater.

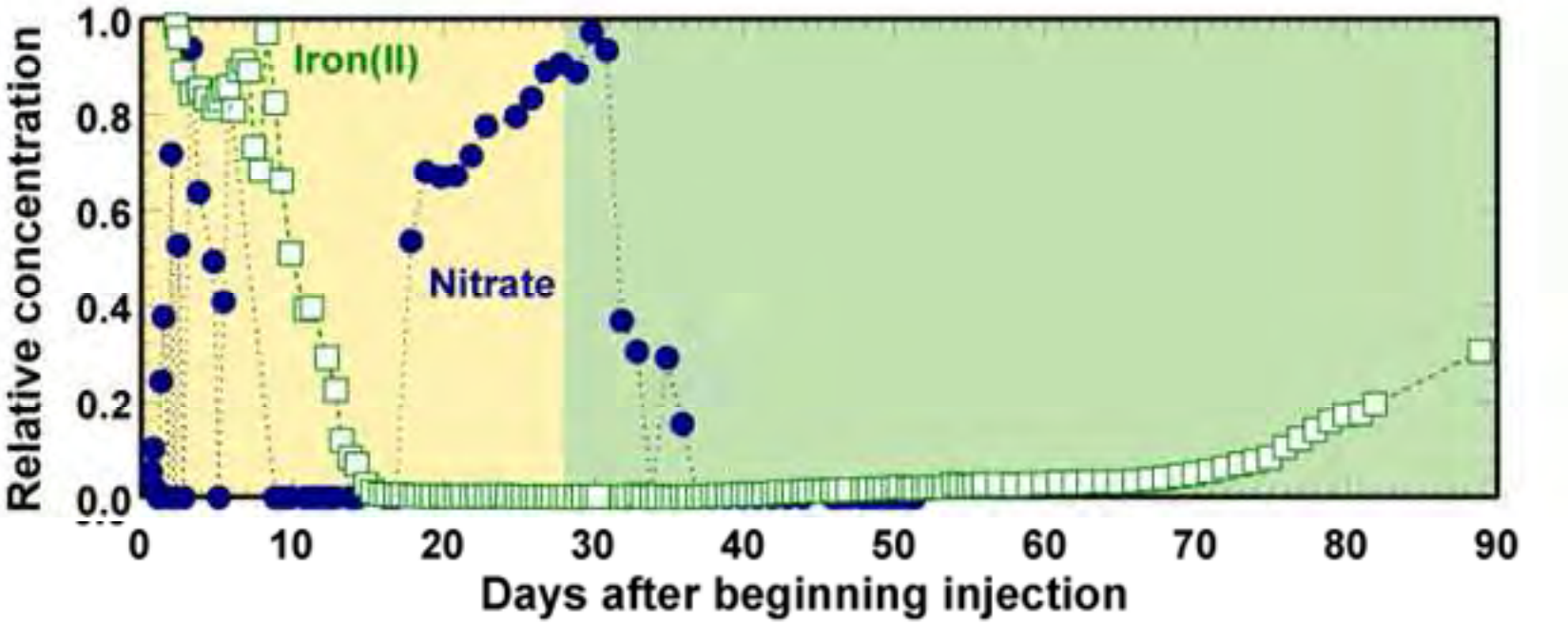


Figuur 6.8: Ijzergehalte in het grondwater

Nitrate immobilizes iron in ground water



Höhn, R et al., 2006 Journal of Contaminant Hydrology, v.88, p. 36-54.



$$20FeS_2 + 52NO_3^- + 5O_2 + 42H_2O \Rightarrow 20Fe(OH)_3 + 40SO_4^{2-} + 28N_2 + 24H^+.$$

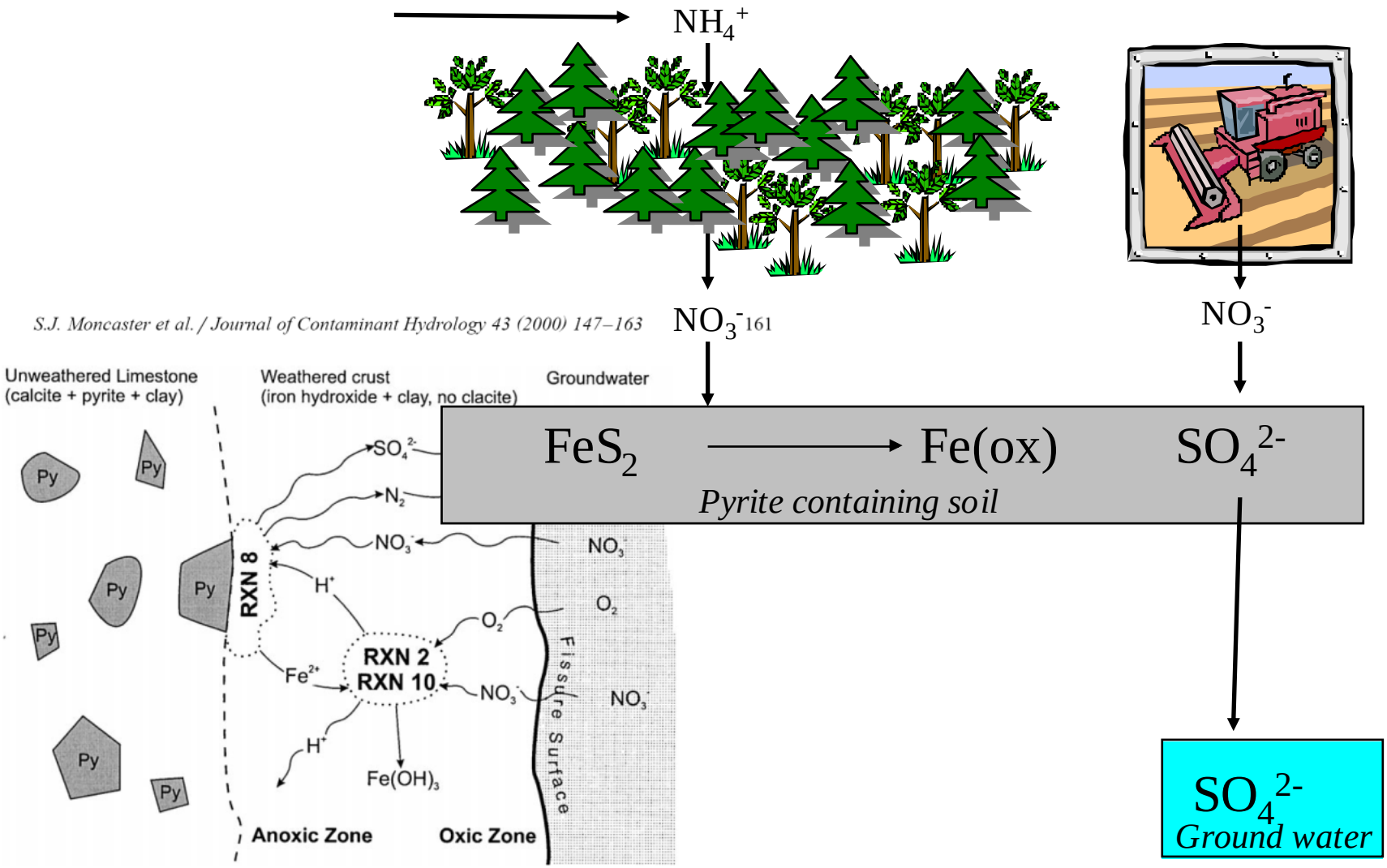
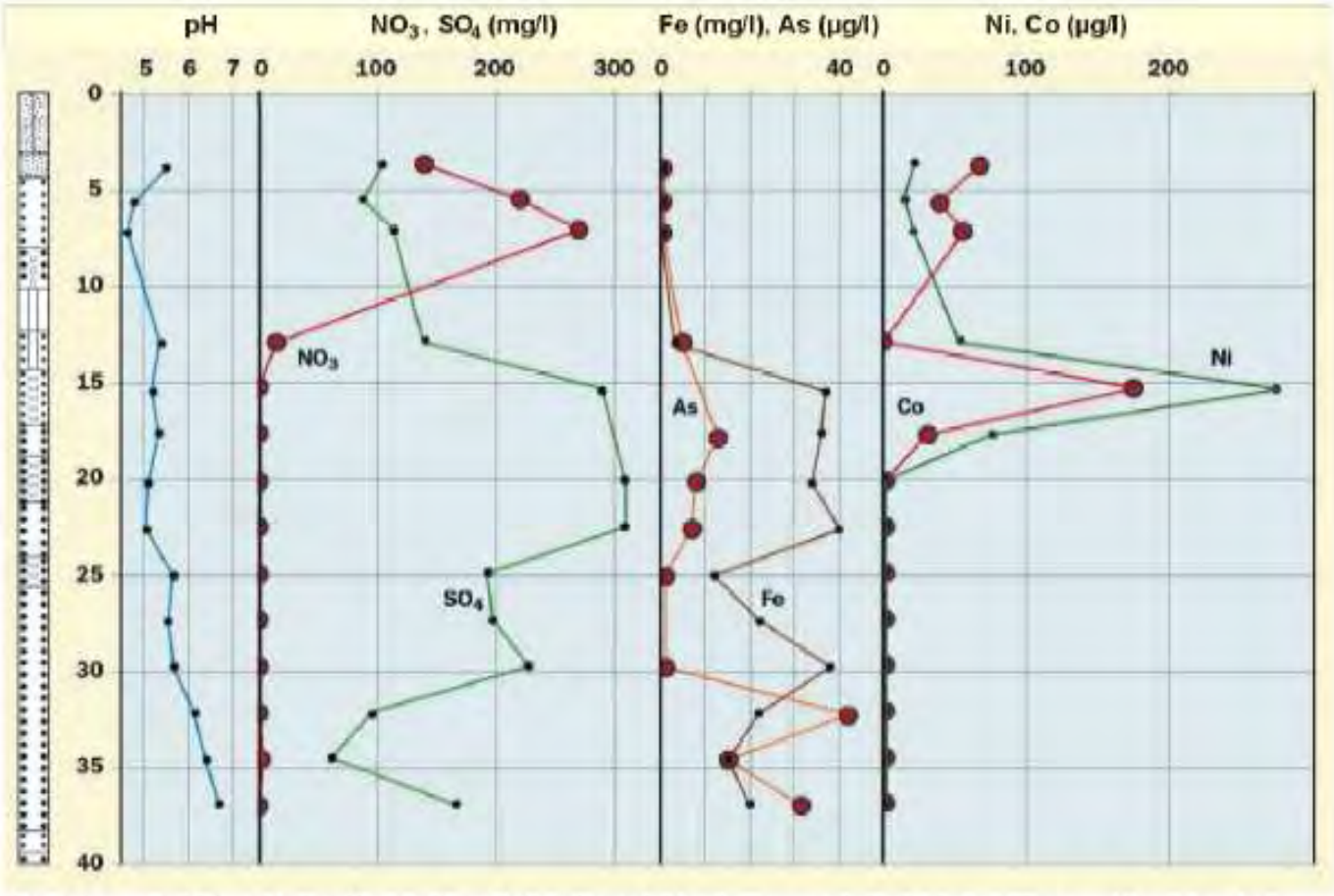
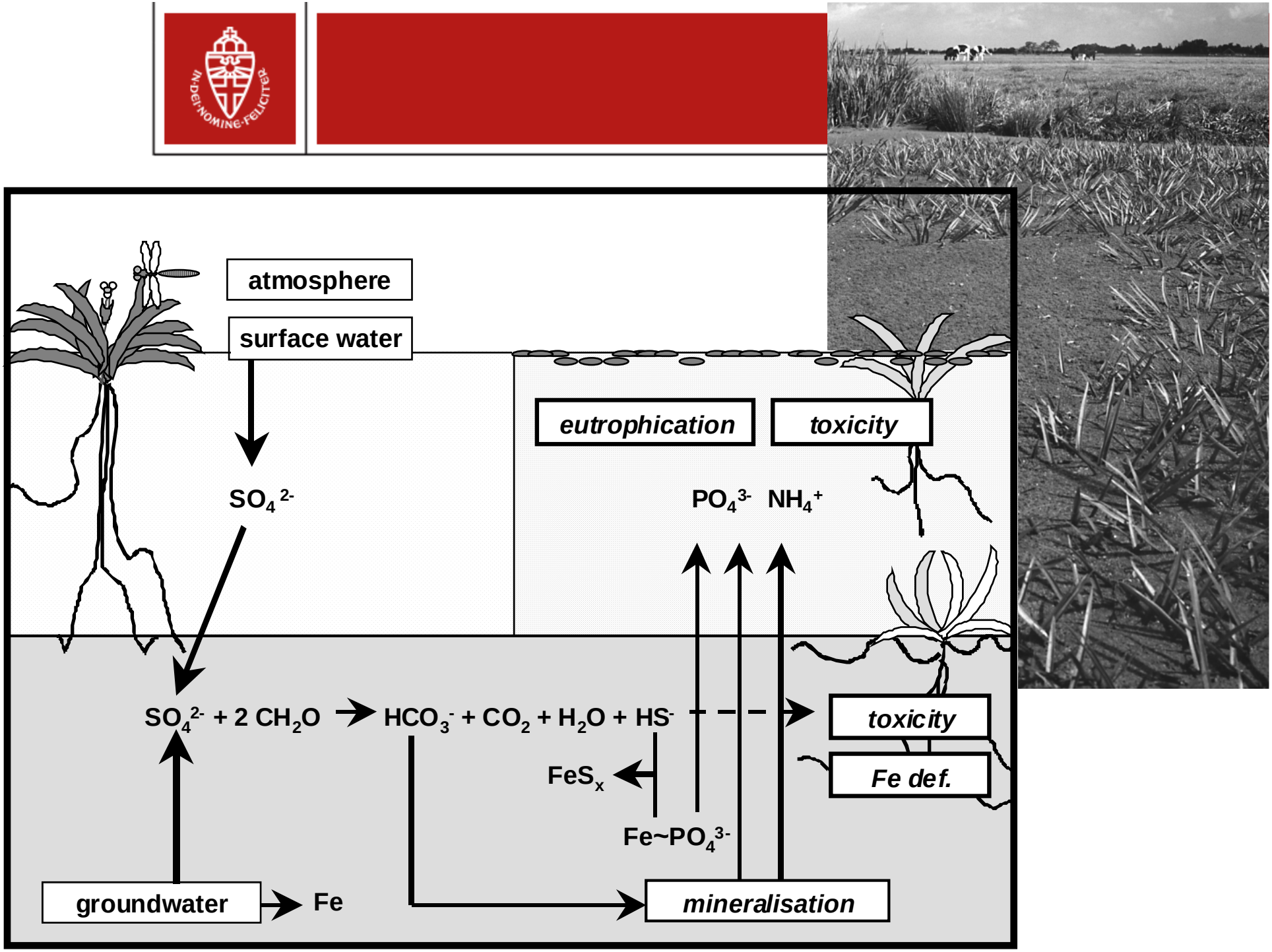
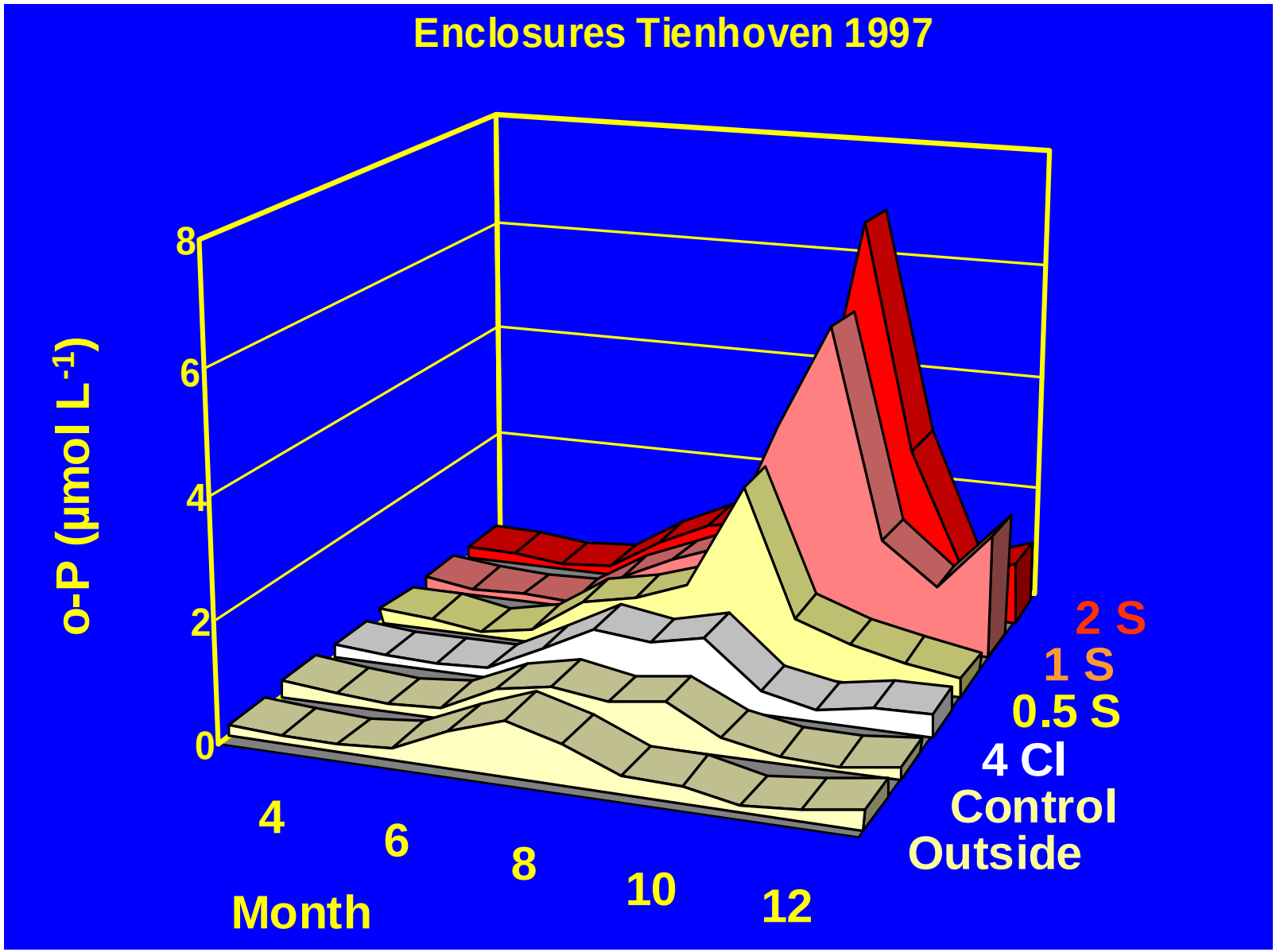


Fig. 5. Conceptual chemical model for the coupled reduction of nitrate and oxygen on fissure surfaces in the shallow confined zone using pyrite as an electron donor.

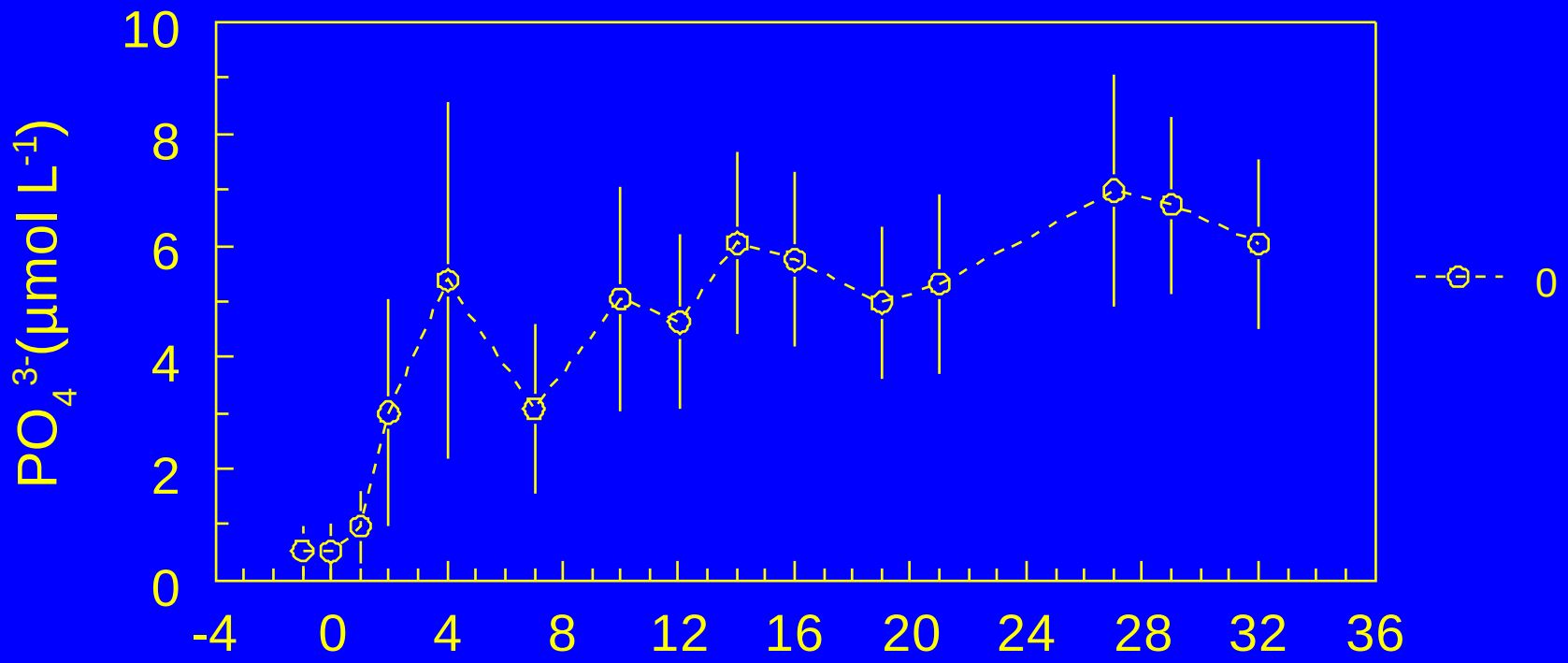


Figuur 3.20: Grondwaterkwaliteitsprofiel van waarnemingsput 40 in het waterwingebied Oostrum. Piekconcentraties van Ni, Co en As werden gevonden onder het nitraat-ijzer redoxfront

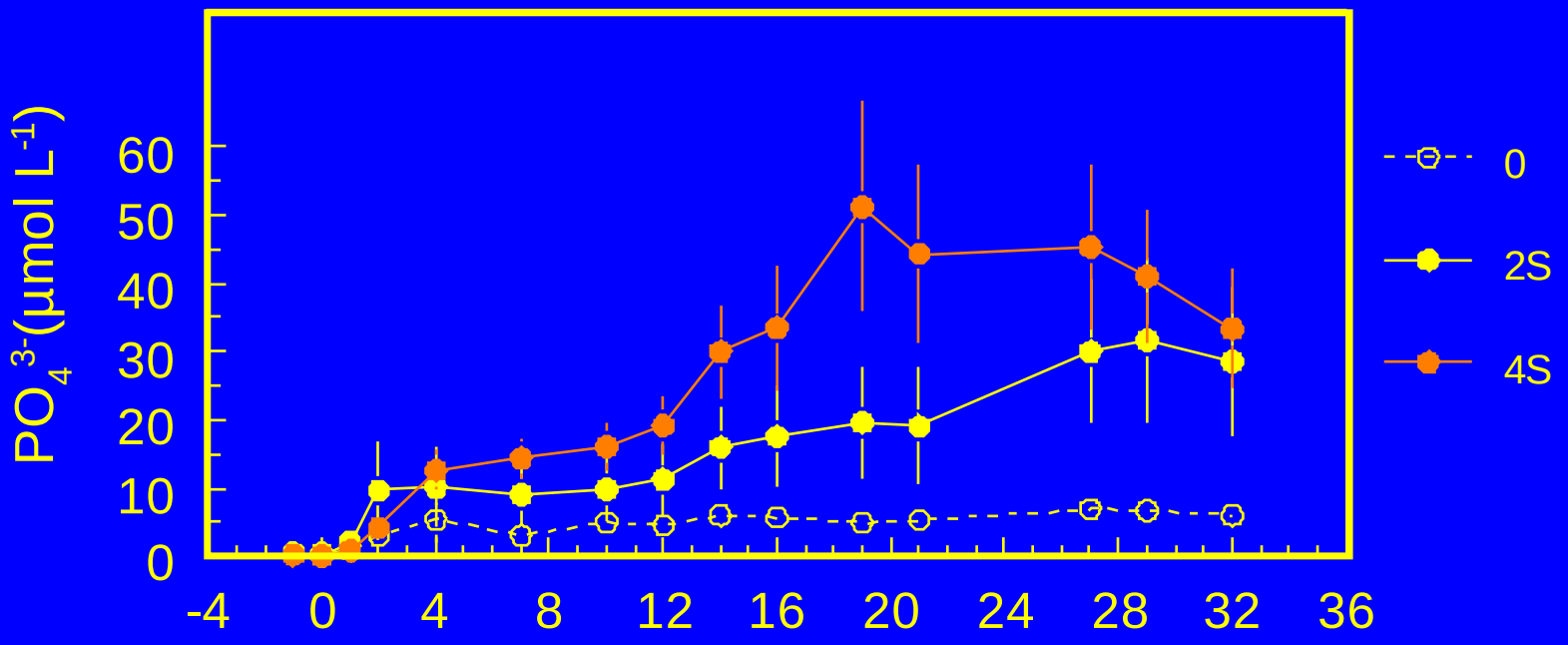

atmosphere
surface water
SO_4^{2-}
eutrophication
toxicity
PO_4^{3-} NH_4^+
$SO_4^{2-} + 2\ CH_2O \rightarrow HCO_3^- + CO_2 + H_2O + HS^-$
toxicity
Fe def.
FeS_x
$Fe{\sim}PO_4^{3-}$
groundwater
Fe
mineralisation


Enclosures Tienhoven 1997
O-P (µmol L-1)
0
2
4
6
8
4
6
8
10
12
Month
2 S
1 S
0.5 S
4 Cl
Control
Outside

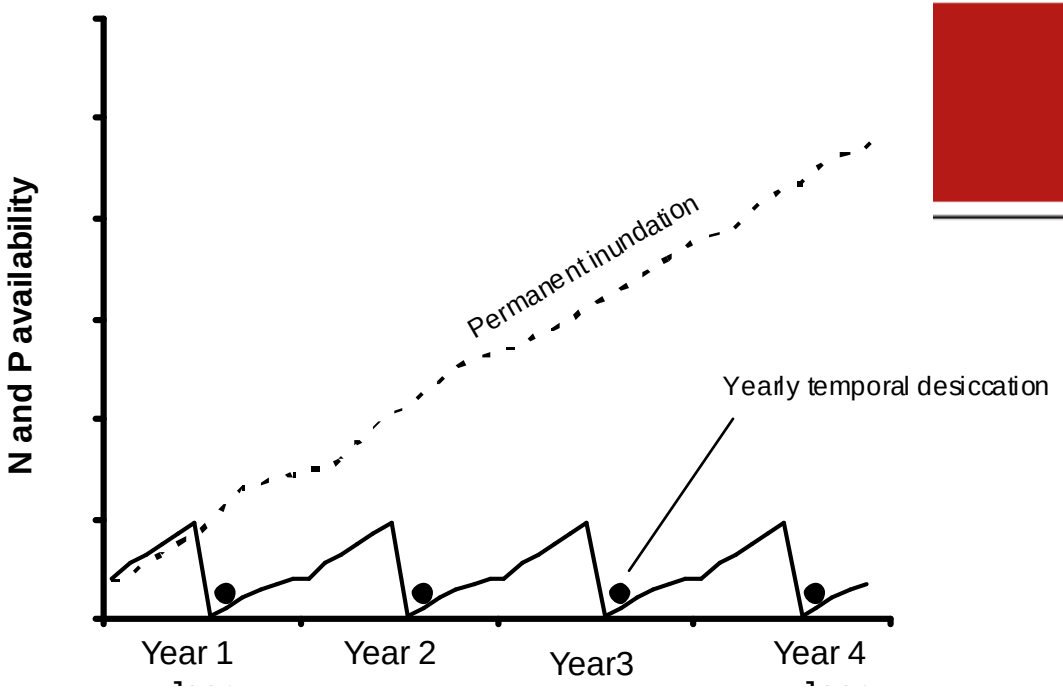
Rewetting of grassland

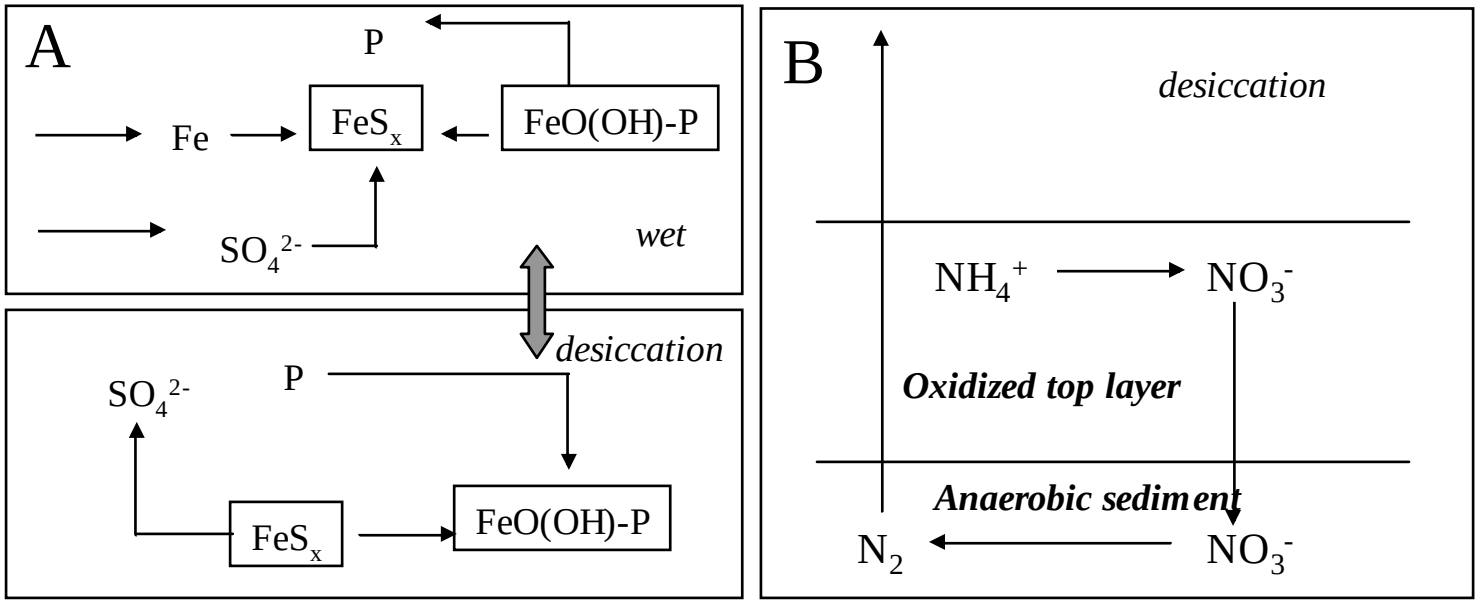


Rewetting of grassland with/without sulphate

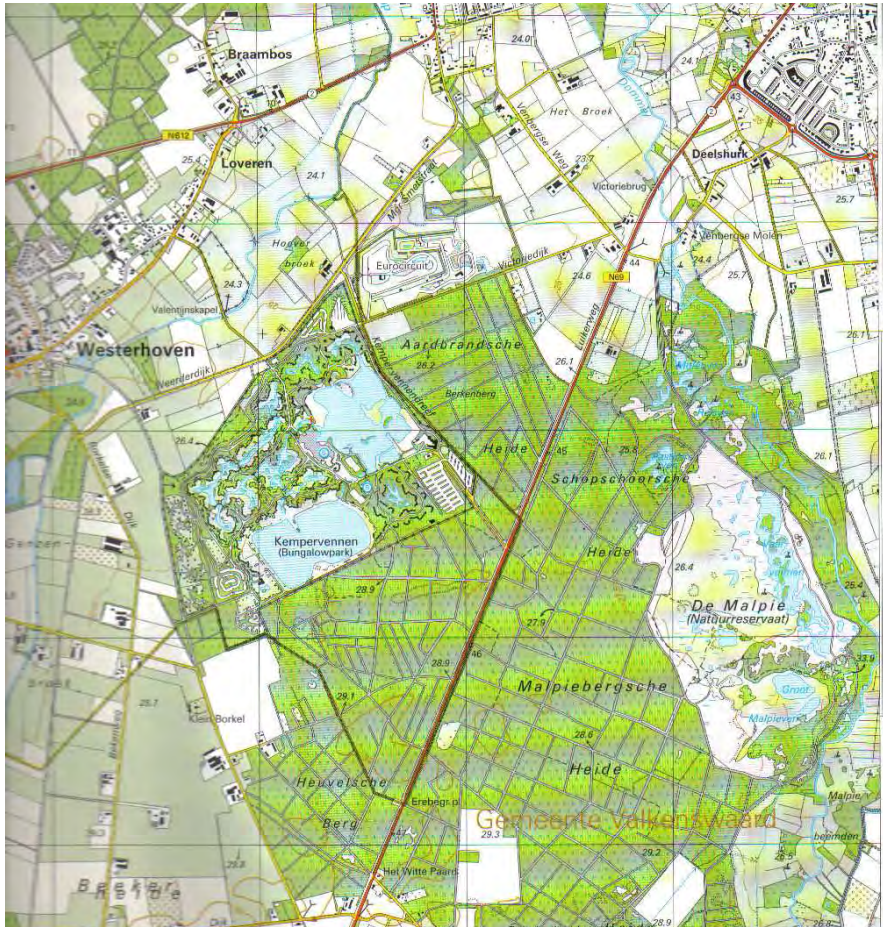


Fosfaat-eutrofiëring !!


N and P availability
Permanent inundation
Yearly temporal desiccation
Year 1
Year 2
Year3
Year 4


A
P
Fe
FeSx
FeO(OH)-P
SO4 2-
wet
desiccation
SO4 2-
P
FeSx
FeO(OH)-P
B
desiccation
NH4 +
NO3-
Oxidized top layer
Anaerobic sediment
N2
NO3-

Changed land use:
Or into pine forest plantation



Species-rich wetlands might easily develop on forest soils on drained land that contain much less nutrients. Removal of the soil top layer is sufficient to create favourable soil conditions

Species-rich wetlands do easily develop on forest soils on drained land that contain much less nutrients. Removal of the soil top layer is sufficient to create favourable soil conditions